Transportation

VOL. 31, NO. 1

THE UNIVERSITY OF MICHIGAN APR 2 1 1960 APRIL 1960

APR 20 1960

Public Roads

A JOURNAL OF HIGHWAY RESEARCH

PUBLISHED
BIMONTHLY BY THE
BUREAU OF
PUBLIC ROADS,
U.S. DEPARTMENT
OF COMMERCE,
WASHINGTON

5

1

18



In this issue: Concrete mixing in 34-E Dual-Drum Pavers.

Public Roads

A JOURNAL OF HIGHWAY RESEARCH

Published Bimonthly

Vol. 31, No. 1

April 1960

BY

BU

TI 16 st

conc duct Dete

time whic

dica

atta

sive

of I

was

strei

mixi excli

mixi

in s

mixi sive

siral

resu

the

 $I_{
m R}^{
m N}$

duct

dual

State

most over

show

quire

the s

ing t

to 12 mitte

loads

that mixi

perm

with the c Th Publ

30, (

time

mixi

E. A. Stromberg, Acting Editor C. L. Fine, Assistant Editor

BUREAU OF PUBLIC ROADS

Washington 25, D.C.

REGIONAL OFFICES

- No. 1. Delaware and Hudson Bldg., Albany 1, N.Y.
 Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island,
 and Vermont.
- No. 2, 707 Earles Bldg., Hagerstown, Md. Delaware, District of Columbia, Maryland, Ohio, Pennsylvania, Virginia, and West Virginia.
- No. 3. 50 Seventh St. NE., Atlanta 23, Ga. Alabama, Florida, Georgia, Mississippi, North Carolina, South Carolina, Tennessee, and Puerto Rico.
- No. 4. South Chicago Post Office, Chicago 17, Ill. Illinois, Indiana, Kentucky, Michigan, and Wisconsin.
- No. 5. 4900 Oak St., Kansas City 12, Mo. Iowa, Kansas, Minnesota, Missouri, Nebraska, North Dakota, and South Dakota.
- No. 6. Post Office Box 12037, Ridglea Station, Fort Worth 16, Tex.
 Arkansas, Louisiana, Oklahoma, and Texas.
- No. 7. New Mint Bldg., San Francisco 2, Calif. Arizona, California, Nevada, and Hawaii.
- No. 8, 740 Morgan Bldg., Portland 8, Oreg. Idaho, Montana, Oregon, and Washington.
- No. 9. Denver Federal Center, Bldg. 40, Denver 2, Colo. Colorado, New Mexico, Utah, and Wyoming.
- No. 10. Post Office Box 1961, Juneau, Alaska.

 Alaska.
- No. 15. 1440 Columbia Pike, Arlington, Va. Eastern National Forests and Parks.

Public Roads is sold by the Superintendent of Documents, Government Printing Office, Washington 25, D.C., at \$1 per year (50 cents additional for foreign mailing) or 20 cents per single copy. Subscriptions are available for 1-, 2-, or 3-year periods. Free distribution is limited to public officials actually engaged in planning or constructing highways, and to instructors of highway engineering. There are no vacancies in the free list at present.

Use of funds for printing this publication has been approved by the Director of the Bureau of the Budget, March 28, 1958.

TE 23 . A37

IN THIS ISSUE

3 articles on Dual-Drum Pavers:	
A Study of 34-E Dual-Drum Pavers	1
Dual-Drum Paver Productivity: A Motion Picture	10
How a Dual-Drum Paver Operates	11
Dual-Drum Paving: Cost vs. Mixing Time .	12
2 articles on Time and Fuel Consumption:	
Time and Fuel Consumption for Highway- User Benefit Studies	16
Fuel and Time Consumption Rates for Trucks in Freight Service	22
New Publication: Highway Progress, 1959	32
Errata	32

U.S. DEPARTMENT OF COMMERCE FREDERICK H. MUELLER, Secretary

> BUREAU OF PUBLIC ROADS BERTRAM D. TALLAMY, Administrator ELLIS L. ARMSTRONG, Commissioner

Contents of this publication may be reprinted. Mention of source is requested.

A Study of 34-E Dual-Drum Pavers

BY THE DIVISION OF PHYSICAL RESEARCH BUREAU OF PUBLIC ROADS 3032

Reported 1 by DONALD O. WOOLF, Highway Physical Research Engineer

This article summarizes data obtained in 16 studies of the mixing of portland cement concrete in 34-E dual-drum pavers, conducted by 13 State highway departments. Determinations were made of the desirable time of mixing and the amount of overload which could be permitted. The results indicated that the highest strengths were attained at a 60-second mixing time, exclusive of transfer time, and that an overload of 10 or 20 percent could be tolerated. It was also found that very little loss in strength of the concrete resulted when the mixing time was reduced to 40 seconds, exclusive of transfer time, but when the mixing time was reduced to 30 seconds a loss in strength of 5 to 6 percent occurred. A mixing time of more than 60 seconds, exclusive of transfer time, was found to be undesirable since it involved waste of effort and resulted in loss of strength without gain in the uniformity of the concrete.

ka, IN December 1957, the Bureau of Public Roads suggested that a study of the production of portland cement concrete in 34-E dual-drum pavers be made by interested State highway departments, to determine the most desirable mixing time and the permissible overload, if any. State highway specifications showed that, exclusive of the transfer time required to move the concrete from the first to the second drum, some States permitted a mixing time of as little as 50 seconds, while other 2. States required mixing times of as much as up to 120 seconds. Some State specifications permitted no overload, but others allowed overloads of from 10 to 20 percent. It was believed that factual information on the effect of mixing time and of amount of overload might permit the more rapid production of concrete without reduction in quality. Lower cost of the concrete in place should then be obtained.

The program proposed by the Bureau of Public Roads suggested that mixing times of 30, 60, and 90 seconds, exclusive of transfer time, be used. Since most States used a mixing time of about 60 seconds, this was taken as a standard of comparison. The 30-second time was suggested as part of the program to provide concrete which might possibly be undermixed; the 90-second time was intended to determine if extended mixing of concrete would abrade the aggregate to such an extent that excessive fines would be produced, causing the strength of the concrete to softer. The States were informed, however,

that these times could be changed to suit their particular interests, if they so desired.

As proposed in the program, many States used an overload of 10 percent in their studies, and in some cases an overload of 20 percent was used. Where the project contractors objected to the larger overload because of possible resultant wear on their equipment and waste of material, the 20-percent overload was omitted.

The suggested program also recommended that for a given combination of mixing time and overload, samples for test be taken from each tenth batch of 90 consecutive batches of concrete. It was further recommended that three samples be taken from each batch sampled, one sample representing each third of the concrete as discharged from the bucket. Specimens for compression and flexure tests were made from certain of the batches sampled and tests for air content, unit weight, and uniformity of composition were made on certain other batches.

Conclusions

The data obtained by the States were so extensive that only a considerably condensed review can be included in this report. Based on a painstaking study of all material reported, the following conclusions have been drawn.

The results of strength tests included in this investigation showed that for 34-E dual-drum pavers, the greatest strength was obtained with a mixing time of 60 seconds, not including transfer time between drums. This mixing time could be reduced to 40 seconds, exclusive of transfer time, with but very little reduction in the strength of the concrete. Reduction of the mixing time to 30 seconds, exclusive of transfer time, caused a reduction in strength of 5 to 6 percent. Concrete mixed for 30 seconds occasionally showed segregation but generally could be placed and finished without difficulty. In some studies it was found desirable to increase the water-cement ratio slightly for concrete mixed for only 30 seconds.

A mixing time of more than 60 seconds, exclusive of transfer time, was found to be undesirable, since it involved waste of effort and resulted in loss of strength without gain in the uniformity of the concrete. Little evidence of excessive abrasion of the aggregate was noted, however, even with mixing times as long as 90 seconds.

Overloading of 34-E dual-drum pavers above their rated capacity caused a reduction in strength of 1 to 2 percent for an overload of 20 percent, and a reduction of 2 to 4 percent for an overload of 10 percent. The greater

reduction for the smaller overload may have been fallacious, or it may have been possible that the mixers used in these tests actually performed better with a greater load. Data to clarify this point were not available.

In studies of the uniformity of concrete produced by 34–E dual-drum pavers, it was found that the quality of concrete depended on the operations preceding the paver mixing operation. If a harsh mix was fed to the paver, extended mixing time still furnished a harsh concrete. If a properly sized and proportioned mix was used, most, if not all, of the mixers studied in this investigation furnished well mixed concrete after only 30 seconds of mixing.

It should be noted that some contractors objected to an overload of more than 10 percent on the grounds that their equipment would not handle it. Also, some contractors were not able to use a mixing time shorter than 50 seconds, due to their inability to supply materials to the payer.

In general, it is believed that the results of the strength tests of concrete were more indicative of the effectiveness of the mixers used than were the results of tests for uniformity of concrete. The tests made for the latter purpose were of considerable value, but if studies of this type should be conducted in the future, a marked increase in the number of tests for compressive strength would be recommended, with elimination of the flexural strength tests and a reduction in the tests for uniformity. If it could be devised, a test for cement content in the mixed concrete which could be made in entirety on the project would be recommended, with another test for water content of the concrete.

Scope of Data

The studies of the effect of mixing time and overload on the quality of portland cement concrete produced in 34–E dual-drum pavers were made by 13 State highway departments; 2 studies were made by each of 3 States, resulting in a total of 16 studies. The locations of the studies are shown in table 1. Information concerning the type of mixer used, the coarse aggregate, the nominal mixing times, and the overloads, is given in table 2.

In this article, data from the studies are presented on the effect of mixing time and overload on the compressive and flexural strengths of concrete. Also reported are determinations intended to show the uniformity (or lack of it) of single batches of concrete, as well as variations from batch to batch of concrete prepared under presumably the same

ting

e no

⁴T sarticle was presented at the 39th Annual Meeting of the Pachway Research Board, Washington, D.C., January 1960.

Table 1.—Highway construction projects in the study of 34-E dual-drum pavers

State	Project number	Date of study	Highway route number	Location
Alabama	I-65-3 (14) (15)	Oct. 1958	U.S. 31	25 miles north of Bir- mingham
California	III-Pla-17-A, Roc. B.	July 1959	U.S. 40	Near Roseville
Delaware	F-12(4) S-US- 48(2).	July 1958 .	Del. 8	Dover, Division St. and Forrest Ave.
District of Columbia.	F-55(1)	June 1958		Irving St. NE.
Florida	I-4-1(2)	July 1958	U.S. 4	Near Plant City
Kansas	F-0 92	Oct. 1958	U.S. 36	Beattie Corner to Nem aha County line
Michigan	1-02-5(6)	June 1958	U.S. 12	Ypsilanti, near Willow Run Airport
Nebraska	F-250(7)	Oct. 1958	U.S. 77	Wymore to Kansas State
New York 1	BT-57-1 I-1119(11)			Near East Chatham 20 miles west of Albany
	I-196(5) I-529(11)			
Virginia 1	F-FG-018-1(1)	Sept. 1958	U.S. 29	Lynchburg bypass
Virginia 2				Highway
Washington West Virginia		Oct. 1958 Oct. 1958	W. Va. 14	Olympia Charleston to airport

Table 2.—Type of paver, aggregate, and principal variables used in the 16 study projects

		Coarse aggi	regate	Principal va	riables
State	Paver	Type	Maximum size	Nominal mixing times used	Overload
			Inches	Seconds	Percent
Alabama		Stone		30-50-90	0-10-20
California	В	Gravel	11/2	30-50-70	0-10-20
Delaware	A	Stone	2	40-70-90	0 - 10 - 20
District of Columbia.	Λ	Gravel	2	30-50-70	0-10-20
Florida	В	Stone	2	30-60-90	0-10-20
Kansas		Sand-gravel	1	50-60-70-90	0-10-20
Michigan	A	Slag	2	30-50-70	0-10-20
Nebraska	C	Stone	1	30-50-60-90	0 - 10 - 20
New York 1	В	Stone	2 2	40-50-60-90-120	0-10-12-20
New York 2	В	Crushed gravel.	2	60-90-120	10-20
Ohio 1		Stone		40-50-75	0-10-20
Ohio 2		Gravel		50-75	0 - 10 - 20
Virginia 1	В	Stone	21/2	30-60-90	0-10-20
Virginia 2	D	Gravel	21/2	30-60-90	0-10
Washington	В	Gravel		45-60	10-20
West Virginia	C	Gravel	2	30-40-50-60	0-10

mixing conditions. The types of tests made by the several States are indicated in table 3.

Some of the States prepared formal reports at the conclusion of their individual studies, while others supplied test results in an informal manner. The data obtained by all States were so extensive that only a review of them can be included in this report. Of particular interest, among data excluded here, were those that would permit comparing the air content of concrete as determined by the Chace air meter and standard pressure or volumetric

meters, and comparisons between the results of slump cone and Kelly ball tests. It is expected that these data will be summarized and reported at a future time, but their inclusion in this report was not considered necessary.

The study was unusual in that it involved considerable effort and cooperation on the part of a number of State highway departments and highway contractors. The skillful handling of difficult field testing operations by the personnel involved, often under unfavorable conditions, contributed greatly to the success and value of the study.

Procedure Problems

In determinations of the mixing time, in this article, the transfer time between drums was not included. It has been stated by some that the concrete is mixed during this transfer process. However, in their reports different States reported different lengths of transfer time, even for the same make of paver, and it was believed that it would simplify the presentation of the material if only the mixing time in the drums was considered. The values reported by the States for mixing times are shown in table 4.

on th

the a

woul

culty

When

subgr

buck

On s

the

shove

found

on le

figure

the

eithe:

So

The original program proposal recommended sampling of every 10th batch for testing. Some States believed that sampling of every 10th batch might be too frequent. and sampled every 20th batch instead Where the testing staff was limited, this allowed ample time for the test procedures Some States questioned some of the methods of test proposed, and modified or eliminated them in accordance with their experience or needs. One State cast only a few specimens for strength tests, and drilled cores from the pavement for the strength tests of record Other differences were found among the individual studies. In general, however, the recommended program was followed suffciently to permit use of most of the data obtained.

One of the most controversial items in the suggested program was the method of obtaining the three samples of concrete representing a single batch or bucket load. It was recom-

Table 3.-Various tests on concrete performed by the States 1

	Tests	for com	pressive	Tes	Tests for flexural		Tests for uniformity of plastic concrete							
State	strength on cylinders ²			strength 3		Washout		Unit	Air content i		Slump	Kelly	Willis-	
	7 days	14 days	28 days	7 days	14 days	28 days	Fine	Coarse	Weight	Pres- sure	Chace		ball	Hime
Alabama. California. Delaware District of Columbia. Florida. Michigan Nebraska.	X X X X	X X X X	X X X X X X	X X X	X X X X	X X X X	X X X X	X X X X	X X X X X X	X X X X X	X X X X X X	X X X X X X	X X X X X X X	X
New York Ohio 1 Ohio 2 Virginia 1 Virginis 2 Washington West Virginia	X	X	X X X X X X	X X	X X X	XXX	X X X	X X X X X	X X X X X X X	X X X X X	X X X X X	X X X X X X	X X X X X X	XXX

¹ No information was received from Kansas. ² Michigan and New York used cores to test compressive strength, flexural strength. ⁴ Alabama and Michigan used the rollermeter method for testing air content.

3 The District of Columbia conducted a 3-day test for



Figure 1.—One of the methods used in obtaining sample concrete.

mended originally that three pans be placed on the subgrade, slightly separated to cover the area over which a bucket load of concrete would be distributed. However, some difficulty was found with this method of sampling. When the pans were placed directly on the subgrade, the wave of concrete from the bucket frequently knocked the pans aside. On some projects, to correct this difficulty, the pans were held in place by concrete shoveled against their sides. Another method found to be effective was mounting the pans on legs about 12 inches high, as shown in figure 1.

Some States adopted the practice of having the bucket load dumped on the subgrade either in a ribbon or in an oval-shaped pile.

ord

the

the

ıffi.

ata

the

ain-

Samples possibly representing different sections of the bucket-load were then taken from the concrete. At first it was questionable whether the samples so obtained could be considered to represent the first, midale, and last third of the concrete batch discharged from the mixer. However, it was pointed out that the first third of the concrete discharged from the bucket might not be the same as the first third of the concrete discharged from the mixer. Due to restraint of the sides of the bucket, the first third of concrete discharged from the bucket may include some of the second third of the concrete discharged into the bucket. For this reason, no consideration was given in this report to differences between the methods used to obtain these

Table 4.—Average mixing time, in seconds, as given by those States where mixing and transfer times were recorded ¹

	Nominal	No ove	erload	10 percent	overload	20 percent	overload	Averag
State	mixing time	Transfer time	Actual mixing time	Transfer time	Actual mixing time	Transfer time	Actual mixing time	actual mixing time
Alabama	30 50	11	30 49	15 11	30 49	11	29	30
Alabama	90	11	79	11	75	11	49 79	49 78
	1 30	10	21	10	23	10	24	23
California	50	10	40	10	39	10	38	39
Comornia	70	10	60	10	60	10	60	60
	1 40	9	41	9	41	9	41	41
Delaware	70	9	70	9	70	9	70	70
orian are	90	9	90	9	90	9	90	90
	1 30	12	29	12	30	12	30	30
District of Columbia	{ 50	12	45	12	45	12	50	47
	70	12	70	12	70	12	69	70
	50	10	39	10	54	10	51	48
Kansas	J 60	10	60	10	57	10	53	57
	70	10	60	10	62	10	61	61
	90	10	75	10	76	10	77	76
Ohio 1	40	8	41	9	43	8	42	42
Onio I	50 75	8	51	9	54	9	51	52
	1 10	9	66	9	66	9	65	66
Ohio 2	f 50	10	50	10	50	12	49	50
	75	10	65	10	65	12	64	65
Vincinia .	30		27		28		28	28
Virginia 1	60	******	58		60	******	60	59
	90		89		87		90	89
Virginia 2	30		29		36			32
virginia 2	60		58	**	63			60
	90		93		96			94

Florida (30, 60, 90 sec.), Michigan (30, 50, 70 sec.), Nebraska (30, 50, 60, 90 sec.), and West Virginia (30, 40, 60 sec.) did not include transfer time in mixing times stated. New York included a transfer time of 9 sec. in mixing times of 40, 50, 60, 90, and 120 sec. No information of transfer time was furnished by Washington (45, 60 sec.).

one-third-bucket-load samples. Although such differences existed, it may be considered that the collective samples for each mixing time and overload are reasonably representative of the entire mixing load.

Effect of Mixing Time on Strength

As shown in table 2, the States used widely different nominal mixing times, and some differences in overloads. There also was a variance in the materials used and in the methods of testing compressive and flexural strengths. To place each set of data on a uniform basis for comparison, the strength obtained for a 60-second mixing time, or with no overload, was adopted as the standard of comparison. Strengths obtained for other mixing times, or for overloads, were then compared with these values.

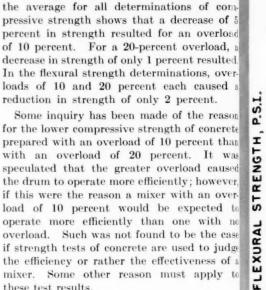
In six of the studies, a 60-second mixing time was not used. To permit comparison of the data obtained with those for the other projects, the determined strengths were plotted against mixing time and a curve drawn through the points. The value shown on this curve at intersection with the 60-second abscissa was taken as the base measure.

To keep the reporting of data concerning mixing time within reasonable bounds, some liberties have been taken in their presentation. The mixing times are shown at 5-second intervals, and a value for strength obtained with an actual mixing time of 48 seconds, for example, is shown for 50 seconds. However, if there was only one determination of strength of concrete for a given time of mixing, this was not shown in the charts. In many instances the elimination of these single values removed wild results and showed to better advantage the trend of the remaining mutually supporting data.

Data reported by each State of the effect of mixing time on the compressive and flexural strength of concrete are shown in figures 2 and 3. The varying strengths reflect the materials used and the methods of testing employed. Some States used cantilever beam testing machines, and obtained flexural strengths much higher than those using center-point loading.

Data averaged for all of the studies to show the effect of mixing time on the compressive strength are plotted in figure 4. The curve in each portion of the figure presents the best considered average. In the lowest portion of the figure, the curve represents an average of the other three curves. Similar curves for flexural strength are shown in figure 5.

The same finding; that the compressive and flexural strengths of concrete prepared with the mixers and materials used were at a maximum for a mixing time of 60 seconds, is evident in figures 4 and 5. Marked increase or decrease in mixing time resulted in a reduction in strength, but this reduction was of no great moment. For a mixing time of only 30 seconds, the compressive strength was reduced only 6 percent and the flexural strength only 5 percent. For a mixing time of 90 seconds, the compressive strength was reduced only 7 percent and the flexural strength only



these test results. Most specimens were prepared, cured, and tested in accordance with standard ASTM methods. No concern need be given to this phase of each investigation, as the data were apparently affected but little by variations in the preparation of specimens. With this accepted, it may be assumed that variations in the strength of the concrete are due to the mixing procedures used, or the weather conditions over which there was no control.

the efficiency or rather the effectiveness of a

mixer. Some other reason must apply to

Figures 6 and 7 present the effect of over-

load on the compressive and flexural strengths of the samples tested. The curve representing

Further study was given to the effect of overload on the compressive strength of concrete, reported in table 5. It was observed that in Florida the strength for no overload was considerably higher than that for 10 percent overload at all ages and for 20 percent overload at an age of 7 days. It was believed that a detailed study of the results from this State might be warranted. It was also noted that in the Virginia No. 2 study and in the West Virginia study the results for a 10percent overload ranged from slightly lower to considerably lower than for no overload, and that no tests were made for an overload of 20 percent. It was believed that these results

migh

9

10

10

STRENGTH 10 10

COMPRESSIVE

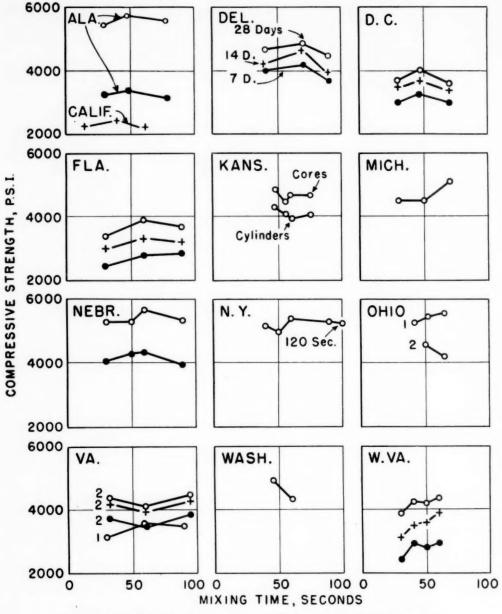


Figure 2.-Effect of mixing time on compressive strength, by State.

3 percent. A reduction in mixing time to strength of about 0.5 percent and no decrease 50 seconds caused a reduction in compressive in flexural strength.

Table 5.-Effect of overload on compressive strength

	Tests at 7 days for unit compressive strength					Tests a	Tests at 14 days for unit compressive strength					Tests at 28 days for unit compressive strength			
State	No overload	10 percent	overload	20 percent	overload	No	10 percent	overload	20 percent	overload	No	10 percent	overload	20 percen	t overloa
		Strength	Strength ratio ²	Strength	Strength ratio ²	overload	Strength	Strength ratio ²	Strength	Strength ratio ²	overload	Strength	Strength ratio 2	Strength	Strengt ratio 2
Alabama California Delaware District of Columbia Florida	p.s.i. 2, 890 4, 010 3, 140 2, 920	p.s.i. 2, 950 4, 020 3, 130 2, 470	102 100 100 85	p.s.i. 3, 320 3, 760 2, 950 2, 760	94 94 94 95	p.s.i. 2, 300 4, 280 3, 580 3, 290	p.s.i. 2, 240 4, 310 3, 560 2, 750	97 101 99 84	p.s.i. 2, 130 4, 120 3, 380 3, 560	93 96 94 108	p.s.i. 5, 720 4, 730 3, 880 3, 760	p.s.i. 5, 260 4, 640 3, 800 3, 320	92 98 98 98 88	p.s.i. 5,740 4,550 3,660 3,940	100 96 94 105
Kansas ¹ Michigan Nebraska Ohio 1 Ohio 2		4,000	96	4, 320	104						4, 560 4, 630 5, 560 5, 370 4, 300	3, 620 4, 920 5, 390 5, 440 4, 050	80 106 97 101 94	4, 150 4, 610 5, 300 5, 450 4, 790	91 100 95 101 111
Virginia 1 Virginia 2 Washington West Virginia		3, 690 2, 560	99			4, 260 3, 640	3, 990	94			3, 620 4, 440 4, 240	3, 330 4, 170 4, 630 4, 100	92 94 	3, 240 4, 660	90
Average			96		100			95		98			94		98

¹ Kansas tested cores at 28 days with the following results; No overload, 5,030 p.s.i.; 10 percent overload, 4,430 p.s.i.; 20 percent overload, 4,530 p.s.i. ² Ratio to strength for no overload

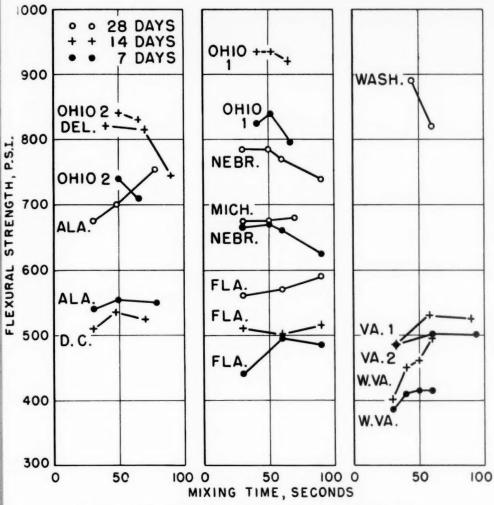


Figure 3.—Effect of mixing time on flexural strength, by State.

might have influenced the general average to an unwarranted extent and that they might well be excluded from consideration.

to no ase dge f a

his

ere

in

ac-

the

ved

oac

10

ted

the

10-

and

f 20

To examine more carefully the results of the Florida tests, the compressive strengths obtained for each combination of mixing time

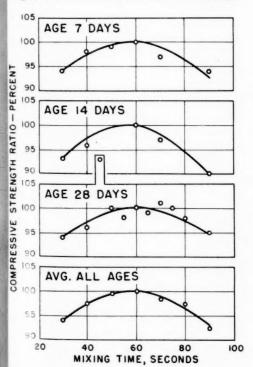


Figure 4.—Average effect of mixing time on compressive strength.

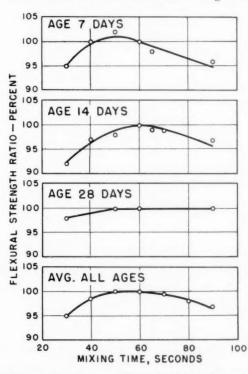


Figure 5.—Average effect of mixing time on flexural strength.

and overload were plotted against age at test. It was believed that if there had been any unusual features affecting the test results. these would be shown by some exceptional behavior in rate of gain of strength. As shown in figure 8, all of the Florida tests made for concrete prepared with 90 seconds mixing time produced an unusual behavior in rate of gain of strength. In two of the three cases, the strength at an age of 14 days was lower than that at 7 days. In the third case, the strength at 7 days appears to be quite low and that at 14 days somewhat high. Why these results had this unusual behavior is not known, but there is indication that they were caused by some feature other than the variables of record and it is believed that these results may justifiably be excluded from consideration. Consequently, in consideration of the effect of overload on compressive strength, all three sets of specimens mixed for 90 seconds in Florida were rejected.

Figure 9 presents revised trends of the effect of overload on compressive strength with the questionable and incomplete data excluded. Even with these data excluded, it was found that the strength for an overload of 10 percent was slightly lower than that for an overload of 20 percent, and both overloads furnished less strength than no overload. The maximum amount of reduction in strength is only 4 percent which, in view of the more rapid production of concrete gained by overloading, may be considered of minor consequence.

In the tests to determine the effect of overload on flexural strength, certain test specimens yielded irregular results, as shown in table 6 and figure 10. In no case, however, were all specimens for a given time of mixing involved, and all data obtained were used to determine average trends for all of the studies.

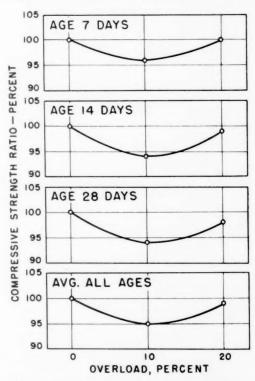


Figure 6.—Average effect of overload on compressive strength.

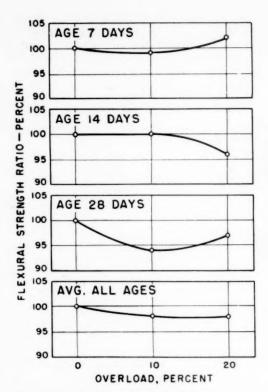


Figure 7.—Average effect of overload on flexural strength.

Effect of Make of Paver

It was hoped that sufficient data could be obtained from the projects using the same make of paver to determine whether that make of paver processed concrete in a manner sufficiently different from the other pavers to warrant comment. It was considered desirable to limit the data used to that representing

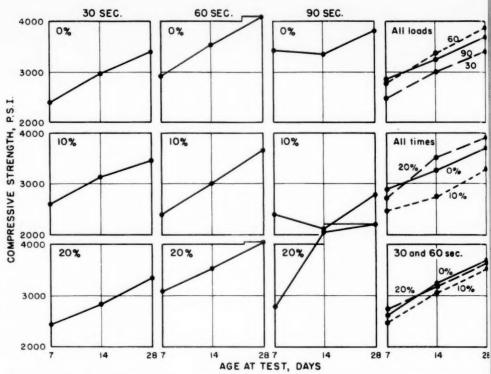


Figure 8.—Compressive strength for each set of variables using Florida test data.

two or more projects and four mixing times. The results obtained for a single make of paver showing the effect of mixing time on strength are shown in figure 11. By comparison with figures 4 and 5, it will be seen that there is little difference between the curves for this single make of mixer and the curves for all makes over the range of 50 to 70 seconds mixing time. It is prob-

able that more difference in effectiveness of mixing will be found between individual mixers of any make than between groups of mixers of different makes. In two of the studies the mixers used were found, on initial inspection, to contain a considerable amount of hardened concrete. Removal of this concrete unquestionably improved the effectiveness of the mixers.

I

wou the

bue

nor air

exp

con

test

con

Hir

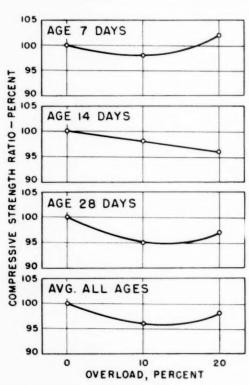


Figure 9.—Average effect of overload on compressive strength excluding questionable and incomplete data.

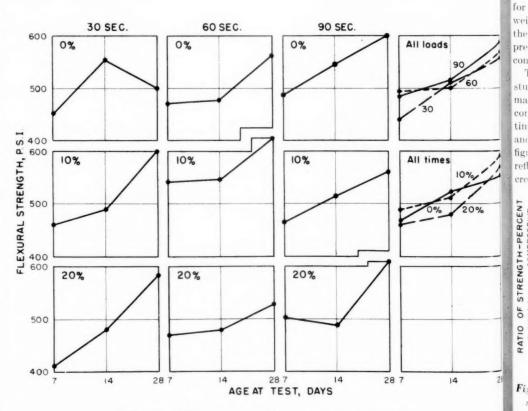


Figure 10.-Flexural strengths for each set of variables.

	Tests	s at 7 days	Tests at 7 days for unit flexural strength					Tests at 14 days for unit flexural strength					Tests at 28 days for unit flexural strength				
State 1	No	10 percent overload		20 percent overload		No	10 percen	t overload	20 percent overload		- No	10 percent overload		20 percent overload			
	overload	Strength	Strength ratio ²	Strength	Strength ratio ²	overload	Strength	Strength ratio ²	Strength	Strength ratio 2	overload	Strength	Strength ratio ²	Strength	Strength ratio 2		
A]abama	p.s.i. 515	p.s.i, 550	107	p.s.i. 575	112	p.s.i.	p.s.i.	00000	p.s.i.		p.s.i. 785	p.s.i. 640	82	p.s.i. 710	90		
Delaware District of Columbia					******	795 545	820 530	103 97	760 500	96 92					*		
Florida Kansas	470	490	104	460	98	525	515	98	480	91	555	595	107	575	104		
Michigan Nebraska	680	640	94	640	94						680 810	665 735	98 90	680 765	100 94		
New York	*****	800	97	835	101	955	875	00	960	101	*****		*****				
Ohio 1	825 720	730	101	730	101	840	845	92 101	820	98					******		
Virginia 1						515	520	101	505	98							
Virginia 2 Washington	505	485	96		******							865		845			
West Virginia	415	400	96			430	470	109									
Average 3	*****		99		102			100		96		****	94	*****	97		

California, Kansas, and New York reported no tests for flexural strength, both 10- and 20-percent overload.

2 Ratio to strength for no overload.

3 The average ratio to strength for no overload at all ages was 98 for

Tests for Uniformity of Plastic Concrete

It would be expected that insufficient mixing would be evidenced by marked differences in the results of tests of the three portions of a bucket of concrete, possibly by greater than normal weight per cubic foot, and by low air content. Excessive mixing would be expected to be detected by excessive fines in the concrete, and possibly by a low air content.

idus

thes

nitia

OUL

effe

O ADS

Almost all of the States made and reported test determinations which were intended to be used to show the uniformity of the plastic concrete. These tests included determinations of the cement content by the Willis-Hime and Dunagan methods, washout tests for fine or coarse aggregates, tests for unit weight of concrete, tests for consistency using the slump cone and Kelly ball methods, and pressure, volumetric, and Chace tests for air content.

The data furnished by the States were studied, and a selection of these data was made to determine the uniformity of the concrete produced with the various mixing times and overloads. For ease in presentation and comparison, these data are shown in figures 12–20. In each figure, sample data reflecting various characteristics of the concrete are shown with reference to individual

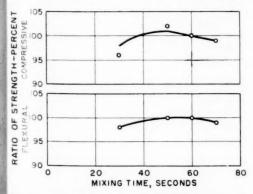


Figure 11.—Effect of mixing time on strength, determined from one make of paper.

combinations of mixing time and overload. Data for the first one-third of the bucket load of concrete are indicated by a circle; for the second third, the data are indicated by a cross; and for the last third, by a triangle. The solid lines in the figures connect the average value for a bucket load.

Generally, the data plotted for each one-third portion is an average taken from three loads of concrete. These loads, obtained from different batches and on different days, could have been influenced by changing weather conditions, characteristics of the materials used, or by the personal equation of the operators. However, the sample loads indicate a general trend which may be considered adequate for this study and are not intended to cover all minute details which might influence such determinations.

For most of the reporting States, data covering tests for unit weight, washout, and air content were available. In the other States, data for slump were available.

Unit Weight

A marked variation in unit weight of concrete for a single batch of concrete or for several batches mixed under the same conditions would indicate either a harsh concrete or insufficient mixing. If a marked variation was found, and the same one-third portion generally had the greatest or least weight of the samples representing the same bucket load, it was assumed that the mixer was not operating properly and was furnishing undermixed concrete. For a given combination of aggregates, high unit weights, closely grouped, indicated well-mixed concrete.

General trends for all data from short to long mixing times were also of interest. If the trend appeared toward greater weight, an improvement in mixing was assumed. If the trend was toward lesser weight, this was taken to indicate overmixing and reduction in size of the aggregate.

Washout

The results of the washout tests were shown by several different methods. In some cases, the States determined and reported the amount of fine aggregate in the concrete or the grading and fineness modulus of the aggregate. In others, the amount of coarse aggregate was determined. Some States reported the grading of all aggregate, and choice had to be made as to which data would give the most information.

The results of these tests were expected to determine if extended mixing of concrete would abrade the aggregate to a marked extent. This could be demonstrated if there was a decrease in the fineness modulus of the fine aggregate, or an increase in the amount of fine aggregate and decrease in the amount of coarse aggregate. Undermixing of the concrete was indicated by the nonuniformity of the distribution of aggregate in the three portions of a bucket load.

Air content

The air content of the concrete was determined by use of pressure or volumetric methods, including the Chace air meter test as one of the latter methods. When available, data obtained with a pressure meter, or a volumetric method using a large sample of concrete, were preferred over data obtained with the Chace air meter.

The air content of air-entrained concrete was believed to be an excellent indication of the thoroughness of mixing the concrete. Insufficient mixing would be indicated by low amounts of air and by variation of the amounts of air between portions of a batch. With excessive mixing, it was believed that some of the air would be lost, but in this case the air in each portion of a batch would be practically constant.

Slump

The slump is a measure of the workability of concrete. A concrete can have a high water-cement ratio and at the same time have a low slump due to harshness of the mix. In very few instances were the concretes produced in these studies found to have poor workability, and it is believed that these cases can be ignored. The slump can be used with other data to deduce whether thoroughness of mixing was obtained.

Other determinations

Other determinations made on portions of a bucket load of concrete included the Willis-Hime test 1 for the cement content of concrete, and the Dunagan method ² for determining the composition of concrete. The Willis-Hime test, made by the District of Columbia, New York and Virginia, yielded disappointing results in that they differed greatly from the known cement content. It was found that the principal reason for the results obtained was failure to dry the samples sufficiently. Since all of the water was not driven off, the cement grains still retained water and were not separated from the sand portion of the mortar during the centrifuging operation. resulted in a test determination showing a low cement content of the concrete.

The District of Columbia made determinations of the composition of the fresh concrete using the Dunagan method. The results varied tremendously and indicated variations within and between batches of concrete which were beyond the realm of the possibility. Without doubt, some feature was overlooked in the performance of these tests which resulted in inappropriate test data.

Review of Uniformity by States

A review of the data for some of the individual State projects was made to determine information of interest with respect to uniformity of concrete. Such information is presented in the following paragraphs.

Alabama

The results from the Alabama project (fig. 12) showed a slight overall decrease in unit weight with increase in mixing time. With an overload of 20 percent, however, higher weights were obtained for each mixing time than for no overload. In 8 of the 9 combinations of mixing time and overload, the last portion of the concrete discharged by the bucket had the greatest weight. These facts collectively were assumed to indicate that the mixer was not operating to best advantage, and that an overload of 20 percent was an aid in obtaining better mixing of the concrete.

Determinations of the material passing the No. 4 sieve in the washout test showed some wide variations within a bucket load of concrete-especially for the 30-second mixing time. Each of the loads had an equal amount of sand, or more in the first one-third of the bucket load than in the second or last third portions. These variations indicated an insufficient mixing for a 30-second period. The general trend for all washout test results showed no increase in amount of fine aggregate with increase in mixing time and overload. This would indicate that even for a 90-second mixing time, there was no more abrasion of aggregates than for shorter periods of mixing time.

The air content tests, using a volumetric method, produced uniform values for the

1 Cement Content of Freshly Mixed Concrete, ASTM

A Method of Determining the Constituents of Fresh Con-

Bulletin, No. 239, July 1959, pp. 48-49.

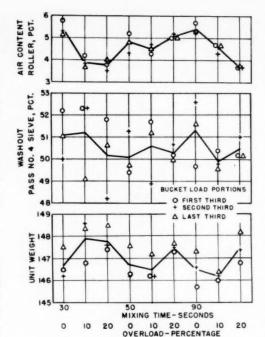


Figure 12.—Test determinations on uniformity of concrete in the Alabama project.

different portions of a bucket load. In two of the three mixing times, increase in loading resulted in a reduction in the amount of air. The air contents for a 30-second mixing time with no overload and with 20 percent overload were the same as those for the same loads at a 90-second mixing time. It would appear from these results that a 30-second mixing time is sufficient to obtain well-mixed concrete, and that further mixing is of little value.

Delaware

Data from the study in Delaware (fig. 13) showed no overall trend for unit weight except for a higher weight for each mixing time with a

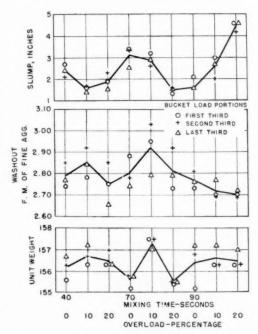


Figure 13.—Test determinations on uniformity of concrete in the Delaware project.

10-percent overload. In 7 of the 9 cases, the weight of the last portion from the bucket was equal to or greater than that of other portions. This indicated that a greater percentage of stone was present in the last portion and further suggested that the mixer was not functioning properly.

in

20-

No

dat

air

cres

Fig

Flo

(fig

Ex

uni

con

the

but

Ne

atio

the

the

gre

OVO

cor

10-

we

of

of

OV

Wa

to

tio

W

va:

Wi

(fi

80

io

PL

In the washout tests, the high value of fine ness modulus of sand for the 70-second mixing time with a 10-percent overload was matched by a similar high value for unit weight. These values were considered as sports, representing a nonuniform condition such as the use of unusually coarse sand. The other values for the washout tests showed no unusual feature other than the prevalence of coarser sand from the center of the bucket load and the progressive decrease in fineness modulus for the 90-second mixing time.

The progressive increase in fineness of the fine aggregate was almost matched by an increase in the slump of the concrete for the batches involved. Although data for the water content of the concrete were not immediately available, the variations in the values for slump were related to the variations in the uni weight values or the fineness modulus of the fine aggregate. Where an increase or decrease in slump occurred, a decrease or increase i unit weight was found or an increase or de crease in the fineness modulus of the sand occurred. Considering all values given, the previously mentioned failure of the mixer t furnish well mixed concrete must be repeated It appeared that extended mixing of the concrete did abrade the aggregate to some extent It was also found that the first sample take from each bucket load generally had a lower than-average unit weight, a finer-than-average sand, and a higher-than-average slump.

District of Columbia

The results obtained in the District of Columbia study (fig. 14) were unique in show

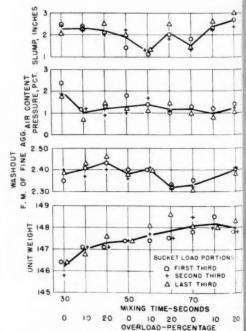


Figure 14.—Test determinations on uniformity of concrete in the District of Columbia project.

crete, by W. M. Dunagan. Proceedings, American Concrete Institute, vol. 26, 1930, pp. 202–210.

.

ing an increase in unit weight for each increase in mixing time and overload except for the 20-percent overload at 70-second mixing time. No corresponding trends were developed in the data for fineness modulus of fine aggregate, air content, or slump. It appeared that the uniformity of concrete was improved by increase in mixing time and load, the additional overload serving to promote the mixing action.

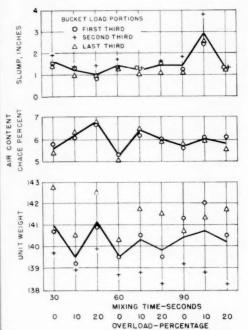


Figure 15.—Test determinations on uniformity of concrete in the Florida project.

Florida

Was

0118

and

Tio

xing

her

hes

ting

for

ron

pro

the

in-

the

ate

tely

for

uni

the

eas

e ii

· de

san

th

er to

ated

con-

tent

akei

wer

iver

p.

how

The results obtained in the study in Florida (fig. 15) in some respects were quite unusual. Except for one nonconforming group of data, uniform results were obtained for the slump of concrete. The tests for air content made by the Chace method, also produced one sport, but otherwise the variations were insignificant. Neither set of data can be used to explain variations found in the tests for unit weight. In the concretes mixed for 60 and 90 seconds, those with a 10-percent overload had slightly greater average weights than those with no overload or 20-percent overload; while in the concretes mixed for 30 seconds, those with a 10-percent overload had the least weight.

In view of the marked variation in unit weight for the separate portions of all batches of concrete, and the fact that the last portion of each bucket load had the greatest weight in 7 of the 9 combinations of mixing time and overload, it appeared that the concrete mix was harsh and failed to respond adequately to increases in mixing time. A possible exception to this may be shown by the low slump. With a slump averaging only 1½ inches, more variation in unit weight must be tolerated within a batch than for higher slump concrete.

Michigan

20

DF DS

Data results obtained in the Michigan study (fig. 16), in which slag was used as the coarse ag regate, reflected in some respects the opinion that slag concrete is usually somewhat

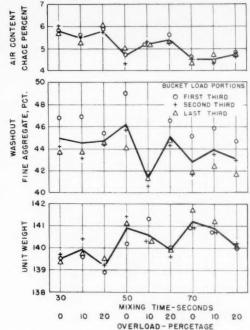


Figure 16.—Test determinations on uniformity of concrete in the Michigan project.

harsh. However, similar behavior was detected in data from other projects in which gravel was used.

In the tests for unit weight, an increase in time of mixing was accompanied by an increase in the weight of the concrete. In the concretes mixed for 50 or 70 seconds, increase in overload resulted in a decrease in the unit weight, and in the concretes mixed for 30 seconds, those with a 20-percent overload had lower weights than those with no overload. These data indicate that an increase in mixing time and elimination of overload may furnish more uniformly mixed concrete for the particular mixer and concrete used in this project.

The washout tests showed a slight decrease in the amount of fine aggregate with an increase in mixing time and overload. The results of the air content tests showed a reduction in the amount of air with increase in mixing time and overload. This could mean that a 30-second mixing period was sufficient to develop maximum air content in the concrete, and that longer mixing periods permitted some of the air to be lost. It is noted that the data for air content and unit weight are associated. An increase of air content was associated with a decrease in weight, and selection of a most desirable set of mixing conditions definitely does not rest in these determinations.

Nebraska

For the study in Nebraska (fig. 17), the aggregate used was a mixture of sand-gravel and limestone. In conducting the washout tests, one determination made was the amount of crushed limestone found in the mixed concrete.

The tests for unit weight of concrete indicated some large variations both within and among batches. The general trend of these data indicated a slightly higher unit weight for concrete mixed for 60 seconds than for the

other concretes included in the study. In 8 of the 9 combinations, the heavier concrete was found in the first portion of a bucket load, indicating that more large aggregate was contained in this portion than in the second or third portions. No relation between unit weight and air content results were found except for one batch mixed for 60 seconds with no overload. This concrete had the highest unit weight as well as the lowest air content.

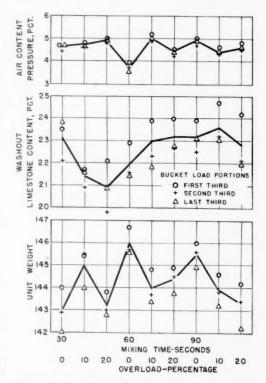


Figure 17.—Test determinations on uniformity of concrete in the Nebraska project.

The Nebraska report stated that a visual inspection of all test batches used did not disclose any poorly mixed concrete. This is of considerable importance as it may indicate that the variations shown in figure 17 may be of no significance with respect to concrete placed on the roadway.

Ohio project No. 1

In the first of the two studies conducted in Ohio (fig. 18), marked variations in unit weight were found, but the data showed no trends which could be associated directly with amount of mixing time or overload. The amount of coarse aggregate recovered from the concrete in the washout tests appeared irregular for the 40-second mixing time, and one group of results for the 50-second mixing time indicated a temporary lack of control at the batching plant. However, the results found for air content appeared to be quite uniform.

It was reported that inspection of the concrete as it was placed on the subgrade revealed only a few batches on which question might be raised regarding uniformity of mixing. Possibly uniformity in grading of the coarse aggregate and in batching the materials were of equal importance to the performance of the mixer.

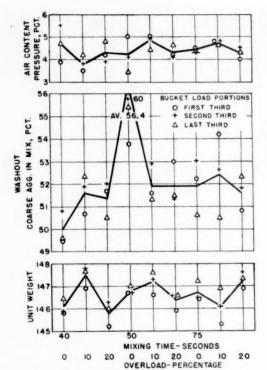


Figure 18.—Test determinations on uniformity of concrete in Ohio project No. 1.



It was reported for Virginia project No. 1 that the concrete was harsh and difficult to finish but this was corrected during the study. However, some of the variations of the data shown (fig. 19) may have been caused by this condition. Consequently, only a few comments on these data may be warranted.

It is interesting to note that the unit weight of the 30-second concrete was reasonably uniform, and that greater variations within batches were found for concrete mixed for 90 seconds. On the other hand, the air content

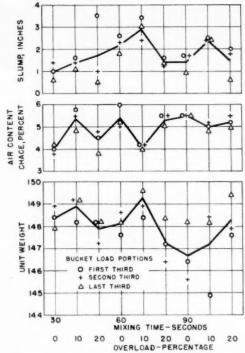


Figure 19.—Test determinations on uniformity of concrete in Virginia project No. 1.

for the 30-second concrete varied more from batch to batch than for the 90-second concrete. In the slump tests, the concrete mixed for 30 seconds with a 20-percent overload had a wide range between portions of the bucket load, but this could have resulted from use of the harsh concrete.

West Virginia

The study in West Virginia (fig. 20) was hampered by cold weather and therefore some of the washout tests were not made. The notable variations in unit weight were

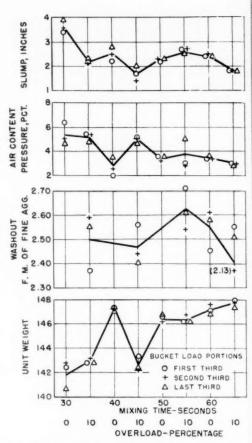


Figure 20.—Test determinations on uniformity of concrete in the West Virginia project.

in close agreement with corresponding variations in air content and slump. In general, the concrete mixed for 50 or 60 seconds was more uniform among batches than the concrete mixed for shorter periods, whereas very uniform concrete throughout a bucket load was found for all mixing times.

Dual-Drum Paver Productivity: A Motion Picture

The Bureau of Public Roads, U.S. Department of Commerce, recently produced a new motion picture, Dual-Drum Paver Productivity. The film, based on field research studies conducted by Public Roads, provides evidence that many contractors can substantially increase job output for any given set of job conditions. The key lies in better control of job operating delays.

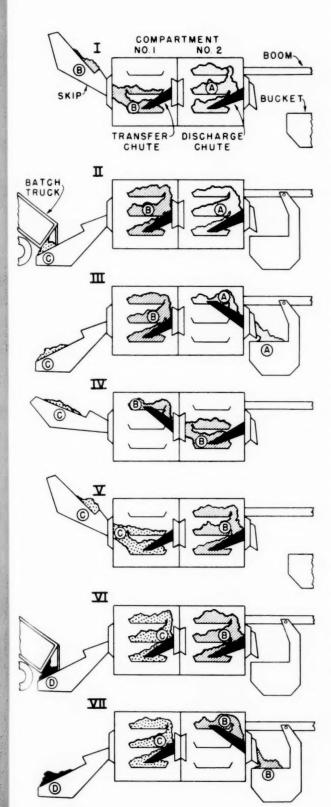
Action scenes from a variety of concrete paving jobs illustrate job conditions and performance factors encountered where paver productivity ranged from low on some jobs to outstanding on others. Illustrations show how batch plant efficiency and capacity as well as haul road variables affect the size of hauling fleet required to supply the paver. Numerous operating delays are highlighted to show how, and to what extent, they effect paver productivity. Actual job scenes show how these delays have been held to a minimum on high production jobs. The simultaneous showing of contrasting action scenes effectively highlights fast versus mediocre batch truck dumping performance at the skip.

Dual-Drum Paver Productivity is a 16-mm. sound and color film with a running time of 30 minutes. Prints may be borrowed for showings by any responsible organization by request addressed to Photographic Services,

Bureau of Public Roads, Washington 25, D.C. There is no charge except for the express or postage fees. Requests should be sent well in advance of the desired showing, and alternate dates should be given if possible. Immediate return after each showing is necessary, so that all requested bookings may be fulfilled.

Prints of the film may be purchased at \$122.83 per copy, the price including film, reel, can, and shipping container, and postage within the United States. Inquiries should be addressed to Photographic Services, Bureau of Public Roads, Washington 25, D.C. Payment should not be sent with the inquiry.

How a Dual-Drum Paver Operates



ia-

al.

as

11-

as

C.

in

ite

at

at

61.

The accompanying series of sketches illustrates the functioning of a dual-drum paver—the machine generally used on-site to mix portland cement concrete for highway pavement—by following a single batch of cement and aggregate completely through the paver. The steps described below are keyed to the Roman numerals at the left of the sketches.

Step I.—The skip is up and batch B is entering compartment 1. Batch A, already in compartment 2, continues mixing. The transfer and discharge chutes are both closed. The empty bucket is returning along the boom.

Step II.—Batches B and A continue mixing in compartments 1 and 2, respectively. The skip is down and is receiving batch C from the batch truck. The empty bucket has returned. The transfer and discharge chutes are still closed.

Step III.—The discharge chute has opened, and batch A is being discharged from compartment 2 to the bucket. Batch B continues mixing in compartment 1, and batch C is in the skip, which is still on the ground. The transfer chute is still closed.

Step IV.—The discharge chute has closed and batch A is in the bucket, riding out the boom to be dumped. As the discharge chute closed, the transfer chute opened, and batch B is being transferred from compartment 1 to compartment 2. The skip is moving upward with batch C. These four steps complete one paver cycle.

Steps V, VI, VII.—These steps correspond exactly to steps I, II, and III, respectively. They are included in the series to show the progress of batch B through the paver from the skip, in step I, to the bucket, in step VII.

The batchmeter

The sequence of steps in the paver cycle is controlled by a batchmeter, a timing device which, at preset time intervals, actuates the successive operations of the paver or signals to the operator that certain operations can proceed. While there is a variety of types, most batchmeters have generally common principles.

With one popular type, the operator engages a control lever on the batchmeter (or keeps it engaged) to begin the paver cycle. The batchmeter then automatically starts the skip hoist, charges water into the drum, and closes the transfer chute. Next the meter signals when the discharge should be made, and the operator opens the discharge chute (if the bucket is ready). Then the meter, at the proper time interval, automatically closes the discharge chute and opens the transfer chute. As the discharge chute closes, and if the batch truck has emptied the next batch of material into the skip and moved clear, the operator engages the batchmeter control lever (or keeps it engaged) and the next cycle begins

With another popular type of batchmeter, the operator raises the skip which, on its way up, trips a lever which starts charging water into the drum, actuates the meter, and closes the transfer chute. After a preset time interval the batchmeter automatically opens the discharge chute, unless the operator intervenes because the bucket is not in position. Once the discharge chute has been opened, the batchmeter automatically closes it and opens the transfer chute. At the same time the meter signals to the operator that he can start the next cycle.

Mixing time

The time settings of the batchmeter theoretically control the mixing time which, for any one batch, is the sum of the times it spends in each of the two compartments. Mixing time is usually defined as beginning when all solid materials have entered the drum. This entry time takes from 3 to 11 seconds from the time the transfer chute closes, depending on the nature and moisture content of the aggregates. Some mixing specifications exclude the time of transfer of the batch from the first compartment to the second, which should take about 9 seconds.

The batchmeter cannot, of course, overcome operating difficulties which delay either charging or discharging. If, at the proper moment, the skip is not ready to go up, or the bucket is not in position to receive a mixed batch, the batchmeter timing device is stopped. When the batchmeter resumes, it runs out the full preset amount of the time interval that was interrupted. During the delay, however, the drum continues to turn on "unmetered" time. As a consequence, overtime mixing occurs, usually for the batch in the second compartment. Thus the true mixing time of any batch is the full preset time of the batchmeter plus any additional time occurring because of delays.

It should be noted that the batchmeter is a mechanical device working under adverse conditions of dust, moisture, and heavy vibration, and cannot be expected to parallel the precision timing of a jeweled watch. In addition, it cannot be ignored that the batchmeter's preset timing can be varied or nullified through actions of the payer operator, either inadvertent or deliberate.

Dual-Drum Paving: Cost vs. Mixing Time

BY THE HIGHWAY NEEDS AND ECONOMY DIVISION BUREAU OF PUBLIC ROADS

Reported 1 by MORGAN J. KILPATRICK, Chief, Construction Economy Branch ing eith driv

effec

port Ii

skip

occi

job

true

the

pro

tol

up

slov

ope

skip

pay

mix

tere

nat

kee

one

pro

of

per rat

cor

sm

of

ing

one

wa

elu

cor

for

m

for

Skilled paving contractors have consistently produced portland cement concrete in dual-drum pavers with controlled mixing time of 45 seconds or less, including transfer time. The increased tempo required for operating the paver with a short cycle and the consequent short mixing time has been achieved in part through use of larger and faster batch trucks, and in part through the contractors' demonstrated awareness of the importance of eliminating unnecessary delays which consume valuable production time.

Monetary savings ranging from 10 cents to \$3 per cubic yard of concrete might be realized if mixing time specifications were reduced to 45 seconds from their present levels of up to 120 seconds. In the current highway program, millions of dollars might thereby be saved annually.

Bureau of Public Roads on-the-job studies of the production of portland cement concrete for highway pavements indicate that some contractors, through adroit management and use of good and well-maintained equipment, achieve sustained high rates of production with dual-drum pavers. The fast paver cycle thus shown to be practical also results in a shorter mixing time for the concrete—less than is now specified by many contracting authorities.

To the engineer the fast cycle poses a problem—that of quality control, usually expressed in terms of mixing time. This is the subject of the article Study of 34–E Dual-Drum Pavers, appearing on page 1 of this issue of Public Roads, in which it is shown that the longer mixing times now commonly specified can be appreciably reduced without affecting the quality of the concrete.

But there is another consideration involved in the fast cycle—that of economy, which is the subject of this article. Starting from a basis of factual knowledge, it will be demonstrated theoretically that reasonable reduction of specified mixing time will result in the production of concrete, by efficient contractors, with savings ranging up to as much as \$3 per cubic yard. Related to the huge highway program now under way, such unit reductions in cost have the potential of saving millions of dollars annually.

Definitions

For clarification, the following definitions are offered. The reader is also referred to the

¹ This article was presented at the 39th annual meeting of the Highway Research Board, Washington, D.C., January 1960.

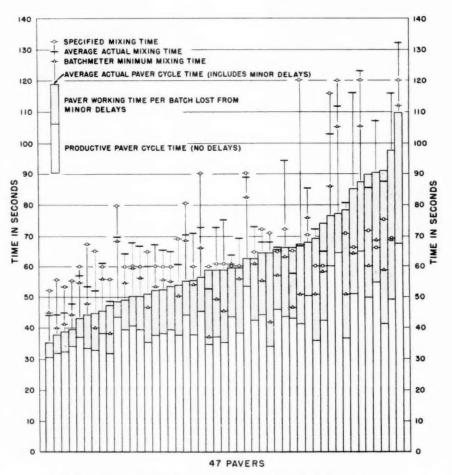


Figure 1.—Performance comparison of 47 dual-drum pavers.

short descriptive article, How a Dual-Drum Paver Operates, on page 11 of this issue.

Paver cycle.—The paver cycle is the sequence of paver operations from one charging of the drum to the next.

Skip cycle.—The skip cycle includes those steps of the paver cycle in which the skip is raised, the batch is charged into the drum, and the skip is lowered to the ground where it is then ready to receive the next batch of material dumped by the batch truck.

Mixing time.—As used in this article, mixing time is the time interval from complete entry of a batch of cement and aggregate into the drum to the beginning of discharge of the same batch into the bucket, including transfer time between the two compartments of the drum. (In the article on p. 1, for reasons explained therein, transfer time was excluded from mixing time.) For any given paver eycle, there is a maximum mixing time that can be obtained when the paver is adjusted and operated in a manner consistent with the manufacturer's recommendations. In this

article it is assumed that paver operations are in accord with such recommendations.

Key to Fast Paver Performance

In the production of portland cement concrete with dual-drum pavers, a short paver cycle means short mixing time and reduction of the time available in which to perform essential operations at the paver. When the paver cycle is extended by delays a longer mixing time inevitably results, thus nullifying the timesaving advantages of operating with a short cycle. Most delays become apparent at the paver skip and it is here that one can find not only a place to measure qualitatively the contractor's management but also the clue to interdependence of mixing time and batch-truck performance.

The key to fast paver performance thus centers around the ability of the paver operator to run a short skip cycle, the batch-truck driver to dump his batches into the skip on schedule, and to a lesser degree on the coordi-

nation among these and other operations in front of and behind the paver. Delays resulting from careless or sluggish performance by either the paver operator or the batch-truck driver, and to a lesser extent by others, can effectively stifle the orderly flow of material, extend the paver cycle, and disrupt both supporting and dependent operations.

If the paver operator is slow in lowering the skip, the time remaining for the batch-truck driver to dump his next batch in the skip may not be enough to prevent a delay from occurring, even though he may perform his job well. If, on the other hand, the batchtruck driver fails to keep his truck close to the skip between batches, does not back up promptly when the skip comes down, or fails to have the dump bed raised or at least started up before backing to the skip, he may be too slow in disposing of his batch. The paver operator will then be delayed in raising the skip to begin a new cycle. In each case the paver cycle is extended by the delay, and mixing time is thereby increased.

Many contractors have successfully mastered the problems of getting essential coordination and performance at the skip, as well as keeping attendant supply lines moving. On one markedly successful operation, sustained production by the paver was recorded at a rate of 98 batches per hour. For intermittent periods lasting up to 2 hours, a 110-batch rate was attained. In other words, a batch of concrete was discharged by the paver every 33 seconds, including delay time. When a small number of extended delays, due to lack of batch trucks, was eliminated from the timing, production was at the remarkable rate of one batch every 30 seconds. Remember, this was an average for extended periods and included minor delays. When no delays occured, individual paver cycles were being completed in 24 seconds or even less, with a mixing time of about 27 seconds.

The operation just cited may seem remarkable, but it indicates what can and is being done. Figure 1 shows the performance data for 47 dual-drum pavers on which production studies, usually of 2-4 weeks' duration, were made by the Bureau of Public Roads. Note that each of the four jobs with the fastest performance had a job average cycle time, including minor delays, of less than 40 seconds. It will be seen that on many other jobs batchmeter settings were sufficiently short that a cycle time of less than 40 seconds could have been achieved if the minor delays had been reduced or eliminated.

Relation of Mixing Time to Paver Cycle

The design of the dual-drum paver is such that two batches are mixed simultaneously during a portion of each paver cycle. The mixing time that can be obtained with any given paver cycle is expressed by the formula:

Mixing time = 2X - D - T - C + L

 $\lambda = \text{paver cycle time.}$

are

con-

aver

tion

es-

the nger

ulli-

ting ap-

one

uali-

also

and

thus

per-

ruck

p on ordi-

ADS

seconds).

T=transfer chute open time (typically 9 seconds).

C =charging lag time, from close of transfer chute when skip approaches vertical until all solid material is in the drum (job averages of 4 seconds have been attained with dry aggregates).

L =discharge lag time, from opening of discharge chute until concrete appears (averages 1 second).

Obviously, any increase in the time taken for the three elements, D, T, and C, will reduce mixing time in relation to the paver cycle time.

As an example of use of the formula, with a 33-second paver cycle and the indicated values:

Mixing time= $(2\times33)-9-9-4+1=45$ seconds.

As previously noted, performance records have shown that on at least one job paver cycles could be completed regularly in 30 seconds which, according to the formula, provided a maximum mixing time of 39 seconds. With the occasional 24-second cycle attained on the job, the mixing time was 27 seconds.

Requirements for a Fast Paver Cycle

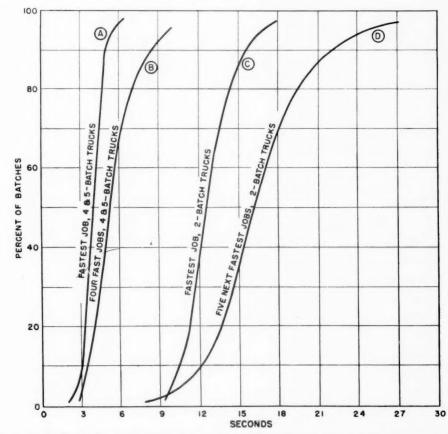
The very fast paver-cycle values and consequent mixing times just cited represent actual performance of a single, rather unusual job. An analysis of the performance requirements for maintaining a short payer cycle, based on averages obtained on a number of fast-moving jobs, demonstrates what is fully practical of achievement.

During the paver cycle the skip must be raised, the mixing drum charged, the skip returned to the ground, and then the skip reloaded. This skip cycle took an average of 20 seconds on all jobs studied and often was accomplished regularly in 15 seconds, but seldom in less. The difference in length of time between the skip cycle and the full paver cycle is available for reloading the skip. To do this, the batch truck must back up and cover the skip, dump its batch, and pull away. The paver operator must see that the truck is clear before starting the skip up to begin a new paver cycle.

It was found, in the Public Roads studies, that batch trucks on fast-moving jobs consistently backed into position to dump into the skip in 2 or 3 seconds. As shown in figure 2, it was observed on a very fast job (curve A) that the trucks dumped and pulled away in 3 to 5 seconds. On several other fast jobs (curve B) up to 85 percent of the batches were dumped in less than 8 seconds. It should be noted, however, that such performances were attained only with 4- and 5-batch trucks. The best performance with 2-batch trucks (curve C) took 15 seconds or less for 85 percent of the batches. On other fast jobs the 2-batch trucks took 20 seconds or less for 85 percent of the batches (curve D).

It was also found that after a batch truck cleared the skip, the paver operator took about 2 seconds before he actually started the new

Combinations of these figures represent possible paver cycle time, from which mixing time can be derived. For example, really fast



D=discharge chute open time (typically 9 Figure 2.-Cumulative frequency distributions of average time to dump one batch into the paver skip and get the truck out.

operation would include 3 seconds for backup, 5 for dumping, 2 for operator's reaction, and 15 for the skip cycle, totaling 25 seconds for the paver cycle and producing a 29-second mixing time. A more representative fast job using 4-batch trucks, with 8 seconds for dumping and 17 for the skip cycle, would have a 30-second paver cycle and a 39-second mixing time.

With 2-batch trucks the fastest dumping was 15 seconds which, with the 15-second skip cycle time, gives a 35-second paver cycle and a 49-second mixing time. More representative of typically fast operation with 2-batch trucks is an 18-second dumping time and a 17-second skip cycle, producing a 40-second paver cycle and a 59-second mixing time.

Long Cycles, Long Delays

Two methods have been used in this article in arriving at a minimum paver cycle time and the resulting mixing time. In the first, data recorded on one very fast operation revealed that a paver ran for a 2-hour period with an average paver cycle of 30 seconds (excluding time lost in a few extended delays), permitting a mixing time of 39 seconds. Mixing time was further reduced to 27 seconds for individual batches.

In the second approach, paver cycle time and mixing time were derived from performance data obtained from a number of well-operated jobs. A 30-second cycle was found to be entirely practicable and a 25-second cycle was attainable, with 4-batch trucks. These cycles produced mixing times of 39 and 29 seconds, respectively. However, no allowance was made for delays in the calculations.

In considering this problem of delays, it was generally found that more time per batch was lost through delays by pavers with a long paver cycle than was lost by those with a short paver cycle.

This paradoxical fact is evident in figure 3. Curve A in the figure represents the average paver cycle time of each of the 47 jobs studied, including minor delays, while curve B represents paver cycle time excluding delays, averaged in groups of five jobs. Curve C, the difference between the values of A and B, represents the delay time per cycle. It will be noted that the longer the paver cycle time, the greater was the amount of delay, and that conversely the jobs with the fastest cycles had the smallest amount of delay.

The most logical explanation for this seemingly paradoxical trend is that as the permissible production potential increased with shorter paver cycles, management became more alert and responsive to the needs and possibilities for reducing or eliminating delays.

Cost Factors

It is an inescapable fact that delays increase costs. With equal assurance it can be said that mixing time requirements influence costs. The cost of operating a paver outfit tends to be fixed and is almost independent, within reasonable limits, of the rate of production. Labor and equipment costs amount to about

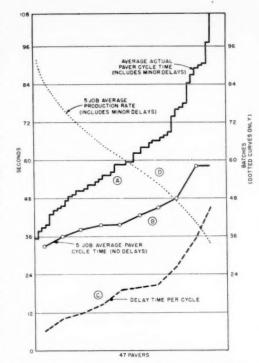


Figure 3.—Comparison of average paver cycle times, including and excluding delay time, for 47 dual-drum pavers.

\$350 per hour, on the average. When production is 50 batches per hour, then, the cost is \$7 per batch. However, if production goes up to 70 batches per hour, which is entirely practicable with good batch-truck performance, the unit cost drops to \$5 per batch. Thus, with such production improvement, the cost reduction per batch is \$2. This amount is a function of the percentage increase or decrease in production and the per-batch difference will diminish as additional batches are added to the hourly production rate. Thus, an increase of 40 batches per hour, from 50 to 90, results in a unit cost of \$3.90 per batch, and a reduction in cost of \$3.10 per batch. In other words, the first increase of 20 batches is worth \$2 per batch, but in the increase of 40 batches the second 20 are only worth \$1.10 per batch.

Data presented in figure 3 also show that hourly production rates, including time lost in minor delays (those of less than 15 minutes each), go down from a high of about 92 batches to a low of 35 per hour as average paver cycle time is increased.

Using data from which figure 3 was derived, for only those pavers which had 50- and 120-second mixing time specifications in force, the production rates averaged 85 and 40 batches per hour, respectively. However, these rates were reduced to 75 and 34, respectively, when the time basis includes certain major delays (those in excess of 15 minutes each) which occurred while a full labor force was employed on these jobs. Using a fixed cost of \$350 per hour, the cost differential between 75 and 34 batches per hour becomes \$5.63 per batch.

Effect of overload on cost

With a fairly common overload of 10 percent, resulting in a 37.4-cubic-foot batch, the

cost differential becomes \$4.06 per cubic yard of concrete. Further adjustment is desirable, under certain circumstances, to account for the variation in batch sizes used for different mixing times. In instances where 50-second mixing time is used a 20-percent overload is usually allowed. This will yield a 40.8-cubic-foot batch. Thus, the difference in production cost becomes \$4.34 per cubic yard when comparing 40.8-cubic-foot batches at a rate of 75 batches per hour with 37.4-cubic-foot batches at a rate of 34 batches per hour.

Effect of increased production on cost

It may be reasonably assumed that hourly production costs are somewhat less when producing 34 batches per hour than when producing 75. The effect of this consideration is to reduce the cost differential. It could be assumed, for example, that the \$350 per hour cost used is for a rate intermediate between 75 and 34 batches per hour, and that the cost would be 10 percent less for the 34-batch rate and 10 percent more for the 75-batch rate. The differential in production cost between the two rates, then, instead of being \$4.06 per cubic yard, would drop to \$2.98 for 37.4-cubic-foot batches.

It would be impractical to obtain specific cost data for every possible rate of output and, in fact, since a number of assumptions must be made, it would be pointless for the purpose here intended. The unit costs developed above, while based on some factual information and reasonable assumptions, are admittedly hypothetical. However, the method does establish a means for computing production cost differentials due to variations in mixing time specifications.

Data from Federal-aid records

Another source of information on this subject is the data compiled from bid prices per cubic yard and specified mixing times for portland cement concrete placed on Federal-aid projects.

The fairly uniform relation of the two is shown (for the year 1957, the latest available in figure 4. It will be noted that from a low bid price of \$15.75 per cubic yard for 50 second specified mixing time there is a gradual increase of both price and mixing time up to \$23.15 for 120-second mixing—a difference. from low to high, of \$7.40 per cubic yard The difference is more apparent than real however. If it actually is a true indication of the differential resulting from the range in mixing time, then it also means that the labor and equipment cost of running a paver outfit exceeds \$700 per hour. Such an hourly cost is unlikely, if not impossible, and cannot be accepted at face value as representing at average.

A more plausible explanation of the \$7.40 differential appears to be that part of it could be charged to the mixing time differences and that the balance represents costs generated by regional differences in design practices, hauling distances, and variations in labor productivity, wage rates, climatic conditions, and materials costs. The last mentioned, in particular, influence bid prices but not paver production costs. It is perhaps not without

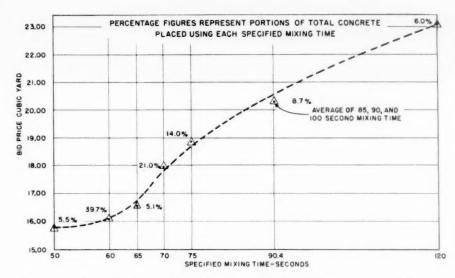


Figure 4.—Distribution of bid price per cubic yard of concrete production according to specified mixing times on Federal-aid projects in 1957.

significance that most States specifying longer mixing times are in the Northeast, whereas those using shorter mixing times are in the South and Southwest where year-round work is possible.

ard

ble,

for

ent

ond

d is

0.8-

in

ard

it a

bie-

our.

irly

pro-

pro-

n is

be

our

reen

cost

rate

ate.

reen

per

bic-

cifie

Dut

ions

the

de-

tual

are

eth-

ting

ions

sub-

per

eral-

o is

able

low

50-

dual

p to

ence.

vard

real.

ation

ge in

abor

utfit

cost

ot be

g al

\$7.40 could sound by uling oductand l, in payer thout

D# D5

Calculation of Potential Savings

The basic objective of this article is to develop quantitatively the potential savings which might result from reduction in mixing time. It is believed that the fixed cost of \$350 per hour for labor and equipment, discussed earlier, offers the most plausible starting point. To allow for variance in production in relation to mixing time, the previously discussed assumptions were used: Production of 34 batches per hour with a 120-second mixing time would cost 10 percent less than the \$350 base; production of 75 batches per hour with a 50-second mixing time would cost 10 percent more. Intermediate values were

taken from a straight-line projection through these points.

With these premises, the production costs per cubic yard of concrete were calculated for a series of mixing times. These are shown in the first two columns of table 1. It was then a simple matter to derive the approximate production cost reductions that are possible by decreases in mixing times, shown in the remainder of table 1.

It should be remembered that the mixing times shown in table 1 include transfer time. For comparisons with data in the article on page 1, which exclude transfer time, about 10 seconds should be subtracted from mixing times used in table 1. As pointed out in the article on page 1, mixing time of 40 seconds produced concrete with very little strength loss as compared with 60-second mixing; and 30-second mixing time resulted in a strength loss of 5 or 6 percent. In terms of table 1,

these values would be 50- and 40-second mixing times, compared to a 70-second base.

Admittedly, it is a bold step to apply the theoretical calculations in table 1 to an entire highway program, but by so doing the point can be driven home. The distribution of concrete production according to specified mixing time on Federal-aid projects (in 1957) is shown in figure 4. It is worth noting, incidentally, that the weighted average of all mixing times was 70 seconds. In the Federal-aid Interstate and primary highway programs, 18 million cubic yards of pavement concrete were laid in 1958, and 20 million would seem a conservative figure to use now.

Working from these bases, the theoretical annual savings in the Federal-aid Interstate and primary programs that would result from reductions in mixing time can be computed. In the first place, if only all higher than 70second mixing times were reduced just to the 70-second level, the resultant annual savings would total about \$41/2 million; reduction of all higher mixing times to 60 seconds would save nearly \$71/2 million. If all mixing times higher than 50 seconds were brought down to the 50-second level, which would result in very little concrete strength loss, the total annual savings would be over \$11 million. Similarly, for reduction of all higher mixing times to a 40-second mixing time, which would result in a strength loss of 5 or 6 percent, the savings would total \$15 million. It will be noted that the reductions of higher mixing times by 10-second intervals produced increasing increments of savings. Further reductions in mixing time, however, would bring diminishing returns in savings. Such further reductions might also bring unacceptable reductions in concrete strength.

There is no question that the assumptions used here are speculative, although they are based on foundations of fact and considered judgment. There is also no question that a considerable proportion of the contracting industry is capable of converting into increased production the time that would be saved by shorter specified mixing times than are now prevalent. The rate of production is to a large extent governed by the performance of the paver operator and the batch-truck driver. Four-batch trucks, able to maneuver quickly and safely with fully loaded beds in hoisted position, are essential for shorter paver cycles, and they are coming into common use. It can be said that the industry is ready for shorter paver cycles, and resulting shorter mixing times of 50 seconds or less. It is encouraging to note that some States have recently reduced their specified mixing times, and others are now contemplating such changes.

Table 1.—Production cost¹ per cubic yard of concrete according to mixing time, and theoretically possible cost reduction resulting from decreases in mixing time

Base mix-	Produc- tion cost	Cost reduction per cubic yard possible by decreasing base mixing time to—											
ing time (seconds)	pe. cubic yard	90 seconds	75 seconds	70 seconds	65 seconds	60 seconds	50 seconds	45 seconds	40 seconds	35 seconds			
120	\$6.69	\$1.85	\$2.36	\$2, 51	\$2.64	\$2.77	\$2, 98	\$3.08	\$3.17	\$3.25			
90	4.84		0.51	0.66	0.79	0.92	1. 13	1. 23	1.32	1.40			
75	4. 33			0.15	0.28	0.41	0.62	0.72	0.81	0.89			
70	4. 18				0.13	0.26	0.47	0.57	0.66	0.74			
65	4.05					0.13	0.34	0.44	0, 53	0.61			
60	3.92						0.21	0.31	0.40	0.48			
50	3.71							0.10	0.19	0.27			
45	3.61								0.09	0.17			
40	3. 52									0.08			

¹ Calculated production costs for labor and equipment. Materials not included.

Time and Fuel Consumption for Highway-User Benefit Studies

BY THE DIVISION OF TRAFFIC OPERATIONS BUREAU OF PUBLIC ROADS

Travel time and fuel savings are two of the benefits that accrue to highway users through highway improvement. Timesavings result whenever highway improvements reduce travel distance, permit higher speeds, or reduce the frequency of speed changes. Fuel savings are effected when improvements reduce travel distance, mitigate any of the resistances encountered by moving vehicles, or reduce the frequency of stop-and-go and slowdown operations.

During 1959 a study of passenger cars and single-unit trucks was conducted to determine the effect of variation of highway surface type and operating speeds on fuel consumption, and the effect of the elimination of both a stopand-go and a slowdown operation on fuel and time consumption at various operating speeds. The study also included determination of the fuel consumed while vehicles were stopped with engine idling. Graphic and tabular material developed from the study and presented in this article will serve in estimating time and fuel benefits accruing through highway improvements.

BECAUSE there was a lack of complete data on the variation in time and fuel consumption for all vehicle types and weights, needed for use in highway-user benefit studies, the Bureau of Public Roads undertook a study in 1959 to determine the effects of highway surface conditions and traffic operations on passenger cars and single-unit trucks. The results of that study, arranged for practical use, are presented in this article. Some of the more general findings, which will also be of interest, are reported in the following paragraphs.

General Findings

Much of the savings in time and fuel enjoyed by users as a result of highway improvement arises because of increased vehicle speeds, smoother riding, and reduction of the frequency of stop-and-go and slowdown operations. On paved surfaces the rate of fuel consumption of passenger cars and singleunit trucks (fig. 1) was found to vary inversely with speed for the slower speeds, with the optimum at 25-35 miles per hour, varying according to vehicle type and gross weight. At higher speeds the rate of fuel consumption increased. On gravel surfaces the relation between rate of fuel consumption and speed (fig. 2) was similar, except that the lowest rate of fuel consumption was at 20-25 miles per hour.

The effect of upgrading from gravel to concrete on the rate of fuel consumption (fig. 3) increased with vehicle speed.

speeds of 15 miles per hour the increase in fuel consumption for the gravel surface was less than 7 percent, but at 45 miles per hour it was over 20 percent for passenger cars and pickup trucks and over 30 percent for singleunit trucks with gross weights of 10,000 pounds or more.

Both the additional time and fuel consumption for stop-and-go operations (figs. 4 and 5) increased uniformly with speed. At any speed the excess time consumption varied directly with weight-horsepower ratio. The additional fuel consumption varied with gross weight for single-unit trucks. The passenger car used in the study consumed more fuel than the heavier pickup truck at all speeds, probably because it was equipped with an automatic transmission while the pickup truck had a manual transmission.

The time consumption for a slowdown of 10 miles per hour (figs. 6 and 7) varied inversely with vehicle speed. The additional fuel consumption of passenger cars for slowdowns varied directly with speed for speeds up to 50 miles per hour, while for single-unit trucks it increased with speed up to speeds of 35-50 miles per hour but decreased somewhat at higher speeds.

Time and Fuel Savings

A major objective of highway-user benefit studies is the evaluation of advantages accruing to users as a result of highway improvements. Two of the more important of these advantages are reduced fuel consumption and reduced travel time. The relation between motor vehicles and the roads they travel is so close that even small changes in the characReported 1 by PAUL J. CLAFFEY, **Highway Research Engineer** wl

spe

inc

hig

bot

sur

fall

the

hig

fue

The

teristics of the road are reflected in the amount of time and fuel needed for highway trips. Minimum values of travel time and motor-fuel consumption are possible only when the roadway is ideally suited for the vehicle and to the traffic volumes in which the vehicle

The ideal highway for such purposes would be straight and level, have a smooth surface. and be so designed that the movements of each vehicle would be completely unaffected by the presence of other vehicles. Although in practice no highway would be built to such improbable standards, all improvements are directed toward making highways less remote from this ideal. The improvement of a highway enables highway-users to complete their trips in less time and frequently with less fuel consumption. Highway-user benefit analyses, if they are to be complete and accurate, must include consideration of these savings.

Travel time savings are brought about through changes in highway facilities which reduce three elements: travel distance, the number of speed changes, and the time lost at traffic signs and signals. Time savings are also brought about by improvements which permit vehicles to be operated safely at higher speeds. Every mile of travel distance eliminated from the highway-user's trips saves time. Elimination of speed changes, such as stops and slowdowns, saves the time consumed while decelerating and accelerating.

Nominal highway speed

Nominal highway speed is defined as the modal operating speed of all vehicles of a given class while moving on sections of a highway where they are not slowed or stopped by highway impedances such as traffic signs and signals, sharp curves, etc. Highway changes which improve sight distance or add to highway capacity generally result in increased nominal highway speeds. On any nor road carrying a traffic volume equal to or bef greater than its practical capacity, the nominal highway speeds of vehicles will be increased by providing greater capacity through the lane widening or additional lanes.

The nominal highway speed for vehicles not having high weight-horsepower ratios will be increased mainly through reduction of grades. An

Reduction of resistance factors

All improvements which lessen travel distance and the resistances to movement at as

¹ This article was presented at the 39th Annual Meeting of the Highway Research Board, Washington, D.C., January 1960. Dr. Claffey is an Associate Professor of Civil Engineering, Catholic University.

constant speed, plus those which reduce speed changes, result in motor-fuel savings, as do improvements which decrease resistance to vehicular movement and reduce the energy requirements needed for operation.

A reduction in resistance to movement and the corresponding reduction in fuel use at any given speed results through improvement which effect reduction of surface roughness, reduction of rate of rise and fall, and reduction of curvature. These improvements, however, frequently permit higher operating speeds which, because of greater air and rolling resistances at higher speeds, result in an increased rate of fuel consumption.

The frequencies of stop-and-go and slowdown time losses are reduced through the provision of grade separations and access control to reduce the number of access points and through construction of additional lanes to relieve congestion. In addition, the frequency of slowdown operations is reduced when curves sharp enough to require vehicles to reduce speed are removed through alinement changes.

eer

unt

ips.

fuel

ad-

to

icle

uld

ace,

ach

rac-

im-

are

note

igh-

heir

fuel

vses,

nust

bout

hich

the

lost

sare

hich

gher

limi-

aves

h as

con-

ting.

the

of a

of a

pped

signs

hway

add

n in-

any

to or

nom-

e in-

rough

hicles

ill be

Savings Used in Benefit Studies

The saving in either fuel or time consumption due to any one type of highway improvement is the difference between the amount consumed if the improvement were made, and the amount if the improvement were not made. Where two or more types of improvement are made at the same location at the same time, the savings for each can be computed by assuming that the other improvement is already completed. For example, if a highway reconstruction project involving both upgrading of surface and reduction of rise and fall is considered, the saving in fuel consumption for operation on the improved surface rather than on the old surface for the new rate of rise and fall will be the same regardless of the changed rate of rise and fall; and the saving due to reduction of rise and fall on the improved surface is unchanged by the fact that the surface had been improved.

The difference in fuel saving for the conditions before and after an improvement is a true measure of fuel benefit even when the particular improvement makes possible higher operating speeds which usually increase fuel consumption. An example is surface improvement. When a gravel road is improved with a high-type surface, the nominal highway speed will increase. The fuel saving that highway-users will realize through surface improvement is the difference between the fuel consumption on the old surface at the nominal highway speed for the old road before improvement, and the fuel consumption at the same speed on the improved surface. The fact that users elect to travel faster on the improved road with a corresponding increase in the rate of fuel consumed does not nullify the saving in fuel use, at the lower speed, made possible by the improvement. Any increase in fuel consumption due to the higher operating speed should be considered dis- separately and included in benefit studies nt at as a negative fuel benefit.

The analysis of user benefits for any highway improvement project can be made most satisfactorily by computing separately the savings for each type of improvement involved and then totaling them. Care must be exercised when summing the savings that the same saving is not counted twice. For example, where a two-lane gravel road is reconstructed as a four-lane divided highway with high-type pavement, both upgrading the surface and increasing the number of lanes permit higher operating speeds with the consequent reduction of time consumption, but the time saving for the higher speed can be included only once.

Required data

For the computation of time and fuel savings resulting from a planned improvement, certain data are required. First, the average gross operating weight of each class of vehicle and the number of vehicles within each class expected to use the route can be obtained by traffic studies and loadometer studies. Second, the information on planned physical changes of the road can be obtained from investigation of the site and by study of the improvement plans.

A third requirement, the effect each type of improvement has on speeds, frequency of speed changes, and the length of stops or delays, can be obtained partially from reported studies (1)2 and from investigation of the traffic operations at the improvement

The fourth requirement, determination of the reduction of resistances to movement at constant speeds, can be made from published graphs illustrating fuel consumption as affected by rate of rise and fall for vehicles weighing 10,000 pounds or more (2) and for passenger cars (3). These data are limited to only certain vehicle classes and gross operating weights, however, and are not sufficiently comprehensive for a general benefit analysis.

Test Vehicles and Procedures

The time and fuel consumption study undertaken by the Bureau of Public Roads in 1959 involved three vehicles-a passenger car, a pickup truck, and a 2-axle, 6-tire, dump truck. These three classes of vehicles accounted for over 98 percent of the vehicle-miles traveled in 1956 by all highway vehicles other than buses and the larger commercial vehicle combinations.3 Such vehicles were being studied at the same time and for the same purpose by the University of Washington, with financial assistance from the Bureau of Public Roads

Data for the passenger car were obtained for a single loading condition, while data for the trucks were obtained for various weight loads-enough to cover the lower range of gross vehicle weights for single-unit trucks. The passenger-car load consisted of two persons, the driver and an observer.

Table 1.—Data for vehicles used in the test operations

	Gross vehicle	Engin	Cross- sec-	
Type of vehicle	weight (pounds)	Net hp.	R.p.m.	tional area ³ (sq. ft.)
Passenger car Pickup truck:	3, 850	123	4, 200	33
No load	3,860	120	4,000	38
Full load Dump truck:	5, 340	120	4,000	38
No load	10,200	89	2,800	54
Half load	15,300	89	2,800	54

¹ All vehicles were 2-axle, 6-cylinder vehicles. The passenger car had an automatic transmission; the trucks were equipped with manual transmissions.
² Frontal area of vehicle, derived by multiplying overall height by overall width.

pickup truck was operated with no load except for the driver and observer, and with a load approximately equal to full load capacity. The dump truck was operated with no load and with one-half full load.

The passenger car was a 6-cylinder 1957 standard 4-door sedan with a 3-speed automatic transmission. At the time of the tests it had been in service for 2 years, during which time it had traveled a distance of 30,000 miles. The weight and additional pertinent information for the three vehicles are given in table 1.

The pickup truck used was a 6-cylinder, manual shift 1959 model with a GVW (gross vehicle weight) of 4,900 pounds. The 6cylinder, 1950 medium-type dump truck had been in service for 50,000 miles. Both trucks were checked on a dynamometer prior to the tests and the efficiency of combustion measured with an exhaust analyzer at a wide range of loads. At the time of the tests the vehicles were operating at near optimum efficiency.

Test run procedures

Data on the time and fuel consumption of these vehicles were obtained from a series of test runs made over a nearly straight section of Virginia route 350 south of Washington, D.C. This is a divided highway with four 12foot lanes of portland cement concrete, with well-built shoulders of firmly compacted gravel 10 feet wide. The test runs were made between two fixed end points set 8,000 feet

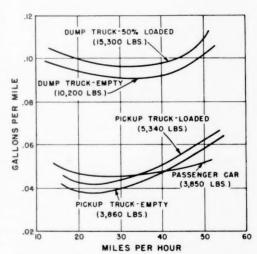


Figure 1.—Fuel-consumption rates at constant speed on a level, straight, concrete surface.

² Italic numbers in parentheses refer to the references on p. 21.

³ Traffic and Travel Trends, 1956, by T. B. Dimmick. PUBLIC ROADS, vol. 29, No. 11, Dec. 1957.

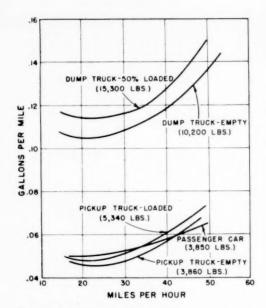


Figure 2.—Fuel-consumption rates at constant speed on a level, straight, gravel surface.

(1.515 miles) apart. These points were at nearly the same elevation and the rate of rise and fall between them was less than 0.2 foot per 100 feet.

The following types of test runs were made between end points of the test section: Constant speed runs on the paved surface at indicated speeds of 15, 25, 35, 45, and 55 miles per hour; constant speed runs on the gravel shoulder at the same speeds; stop-andgo runs on the paved surface at indicated operating speeds the same as for the constant speed runs; and slowdown runs (10 mile per hour speed reduction only) on the paved surface at the same operating speeds. runs of each type were made for each vehicle and load in each direction at each of the given speeds. The idling fuel consumption was obtained for each vehicle at engine speeds of 450, 550, 650, and 750 revolutions per minute.

The runs were made by driving the vehicle over the test section, measuring the amount of travel time and fuel consumed between end points and recording the direction of travel, time of day, fuel temperature, and run speed

as indicated on the vehicle speedometer. For the constant speed runs no other data wer taken. On the stop-and-go and slowdow runs the vehicle was brought to a stop or th speed reduced by 10 miles per hour an immediately accelerated back to schedule speed, as many times as possible, passing bot end markers at run speed. Additional dat recorded for these runs were the time during which acceleration took place after each sto or slowdown, the number of stops and slow downs, and the number of gear changes for each acceleration. The rates of speed chang used for both the stop-and-go and slowdow operations during deceleration and accelera tion were those of the typical driver under ordinary conditions (5).

Recording the date and time made it possible to determine wind direction and velocity at the time of each run by reference to wind data collected by the U.S. Weather Bureau at a nearby station.

The first step in the analysis of the field data was to compute the true speed of each test run. The indicated run speeds, read on the speed

el

a

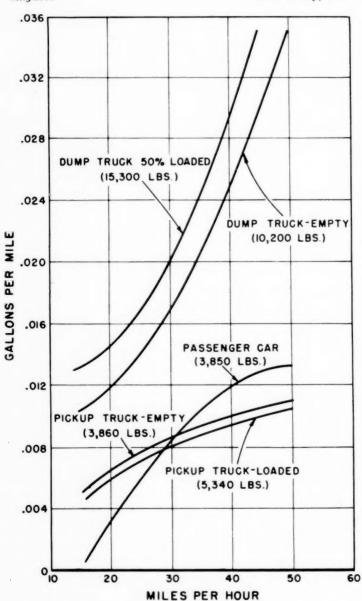


Figure 3.—Savings in fuel consumption at constant speeds effected by improvement from a gravel surface to a concrete surface.

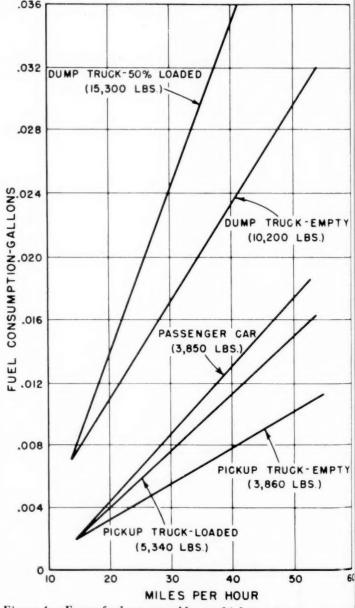


Figure 4.—Excess fuel consumed by a vehicle coming to a stop and then returning immediately to former speed.

ometer, were recognizedly inaccurate but were used during the test because it was easier for the driver to maintain a given speed consistently if he had a definite speed to attain rather than attempting to hold the speedometer needle at such a point on the dial that the run speed would be the true speed. The true speed was computed from the known run distance and the run time recorded for the constant speed runs.

Wen

dow

or th

dule

boti

dat

lurin

sto

slow

s for

hang

dow

elera

unde

DOSS

locit

Will

aua

data

t run

peed

Fuel consumption was measured directly and accurately by noting the amount of fuel drawn out of the reservoir of a burette type fuelmeter. Since the volume of fuel measured varied with the temperature, all fuel readings were corrected to 30° C. (86° F.)—the average fuel temperature during the period of the tests.

Application of Test Results

Corrected fuel-consumption values in gallons per mile were computed for each constant speed run on both the paved and gravel surfaces. Curves drawn from the averages of these values for each run speed for each vehicle type and weight, plotted against true speed, are shown in figures 1 and 2.

The curves in figures 1 and 2 may be used to estimate the change in rate of fuel consumption in gallons per mile which will result when nominal highway speeds are increased through highway improvement on roads carrying traffic volumes somewhat less than their capacity volume. Since nominal highway speed is the average operating speed between points where vehicles are slowed or stopped by highway impedances, the application of these

curves is not restricted by the effect of such highway impedances.

In the case of highway improvements where more lanes are to be added to provide greater capacity, when capacity before improvement is less than the 30th hour volume, figures 1 and 2 may be used to estimate the fuel consumption after improvement when vehicle speeds are relatively uniform. However, the lower speeds before improvement are largely due to congestion and include frequent decelerations and accelerations. The rate of fuel consumption before improvement may be estimated by adding to the values found in figures 1 and 2 the amount of additional fuel consumed by slowdowns. The average number of slowdowns may be determined by making suitable speed-delay studies over the route before improvement, and the additional fuel consumption due to a slowdown may be estimated by using the curves in figure 6 (p. 20).

The curves presented in figure 3 show the fuel savings in gallons per mile effected by improvement from a gravel surface to a paved surface. The ordinates of these curves equal the difference between the fuel consumption for operation on a paved surface and operation on a gravel surface at the same speeds.

In using figure 3, the saving due to surface improvement should be read from the curves for the nominal highway speed of the gravel-surfaced road before improvement. A reduction in road roughness, of course, will permit higher speeds and most users take advantage of this even though higher speeds increase fuel consumption for speeds above approximately 35 miles per hour. It is at the discretion of

the highway user whether he operates on the improved surface at the same speed as on the rougher surface and saves on fuel use, or operates at a higher speed and pays for the higher speed (and thus time saving) through increased fuel consumption. In either case the saving is made available to the user. The nominal highway speed of modern vehicles on a gravel or loose surfaced road is between 30 and 35 miles per hour; for any particular road under study it should be obtained by making a spot speed study.

Stop-and-go operations

The additional fuel consumed for a stopand-go operation was found by dividing the number of stop-and-go operations made on each run into the difference between the amount of fuel used for the stop-and-go run and the average amount of fuel used for the constant speed runs on the paved surface at the same run speed. This difference was the additional amount of fuel used by a vehicle to come to a stop and accelerate back to the constant speed. The fuel consumption curves for stop-and-go operations at various speeds are presented in figure 4.

A similar procedure was used to compute the additional time consumption for a stop-and-go operation. Figure 5 shows curves of excess stop-and-go time consumption as a function of true speed. The time and fuel consumption shown in figures 4 and 5 do not include the time or fuel consumed while a vehicle is stopped, but only the additional consumption for the actual stop-and-go maneuver.

Engine idling consumption rates

The idling fuel-consumption rates of the test vehicles are presented in table 2. The data shown were obtained with the vehicle stationary and the engine warm. For the trucks, the rates were obtained in forward gear with the clutch disengaged. The rate for the passenger car equipped with an automatic transmission was measured with the transmission in neutral position and also in drive position with the brakes set. Idling fuel-consumption values are given for four different engine speeds—the average of these being recommended for use in benefit studies.

Figures 4 and 5 and table 2 are particularly useful for estimating the savings which will result if an intersection controlled by traffic signals or stop signs is eliminated through construction of a grade separation structure.

Table 2.—Fuel consumption rates for idling vehicle

Fuel consumption in gallons per minute

	Fuel con	nsumptio	on in gal	lons per	minute
Engine revolutions	Pa	ssenger c			
per minute	Trans- mis- sion in neutral	Trans- mis- sion in drive	Average	Pick- up truck	Dump truck
450	0.005 .006 .006 .007	0.005 .008 .009 .014	0.005 .007 .007 .010	0.006	0.009 .010 .011 .013
Average	. 006	. 009	. 007	. 007	. 011

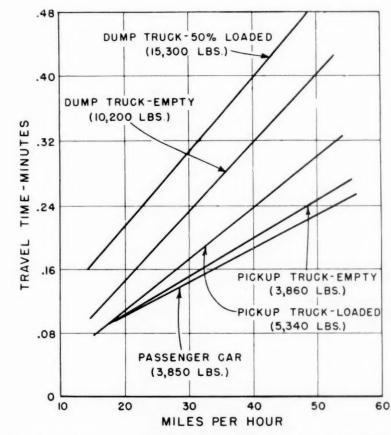


Figure 5.—Excess time consumed by a vehicle coming to a stop and then returning immediately to former speed.

op and

POADS

Slowdown operations

The additional fuel and time consumption curves for a slowdown of 10 miles per hour with immediate resumption of speed, at various speeds, are shown in figures 6 and 7. Periods of operation at reduced speed are excluded. The procedures used for computing these values due to slowdowns were similar to those used for computing the fuel and time consumption of stop-and-go operations.

The applicability of the curves in figures 6 and 7 is limited to improvements that eliminate highway impedances which cause vehicles to reduce speed by about 10 miles per hour. This limitation is not serious, however, since most slowdowns of importance in highwayuser benefit studies are about 10 miles per hour. Preliminary analysis of data taken from extensive speed-delay studies made in 1958-59 with a passenger car showed that speed reductions of up to 3 miles per hour were a normal part of uniform driving and were not eliminated through highway improvements, and that the average of the speed reductions in excess of 3 miles per hour was about 10 miles per hour. In addition, it was recently established that the average speed reduction of motortrucks when slowed by highway or traffic impedances is 11.4 miles per hour (6).

The curves in figures 6 and 7 may be used to estimate savings in fuel and time consumption through the elimination of a variety of speed reduction factors. In the case of a curve elimination, test runs should be made before improvement to determine the average amount of slowdown caused by the curve. Where crossroads or driveway entrances are to be eliminated, test runs should be made to establish the average percentage of driveways at which through vehicles are forced to reduce speeds because of other vehicles entering or leaving, and the average value of such speed slowdowns.

If the average speed reductions found for curves and driveway entrances are between 8 and 12 miles per hour, figures 6 and 7 may be used to compute fuel and time savings. If the average speed reduction is more or less than 8 to 12 miles per hour, the fuel and time savings may be estimated by assuming that the magnitude of these savings is proportionate to the magnitude of the speed change.

Practical Illustrations

Two examples will illustrate how figures 1–7 and table 2 may be used to compute the fuel and travel-time savings arising from particular improvements.

Example A.—On a 10-mile length of 2-lane road 24 feet wide, the existing gravel surface is to be replaced by a concrete pavement. Average annual daily traffic on the route is 4,000 vehicles per day; 80 percent of the vehicles are passenger cars and 20 percent are 2-axle, single-unit trucks having an average gross vehicle weight of 10,000 pounds. The nominal highway speed on the route before improvement was found to be 35 miles per hour for all vehicles. It is expected that this will be increased to 45 miles per hour after improvement. Compute the average annual

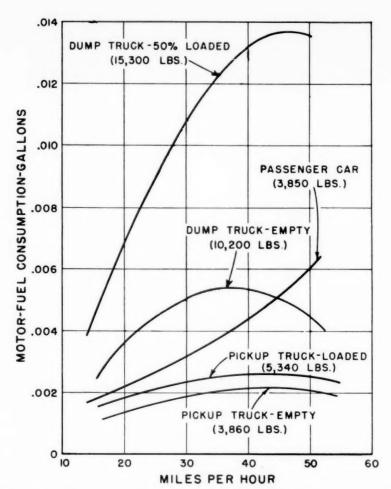


Figure 6.—Excess fuel consumed by a vehicle reducing speed by 10 miles per hour and then returning immediately to former speed.

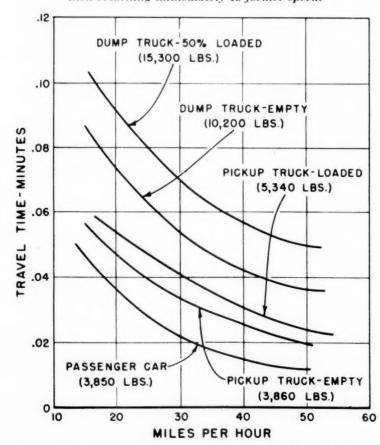


Figure 7.—Excess time consumed by a vehicle reducing speed by 10 miles per hour and then returning immediately to former speed.

20

PUB

fuel

impr

Truck

impr

per 1

Fron

tion

m.p.

passe

prov

Truck

Th

to 13

this

Ea

is pl

divid

traffi

The

4,000

vehic

80 p

senge

nnit

10,00

on th

the

move

num

deter

perce

Ar

fuel savings which may be attributed to this improvement.

Solution.—Annual number of vehicles using the route:

From figure 3, fuel savings due to surface improvement at nominal speed of 35 miles per hour are 0.010 gal. per vehicle-mile for passenger cars and 0.021 gal. for trucks. From figure 1, the increases in fuel consumption due to speed increase from 35 to 45 m.p.h. are 0.003 gal. per vehicle-mile for passenger cars and 0.004 gal. for trucks.

Annual fuel savings for the 10-mile improvement:

Passenger cars.... 1, 168, $000 \times 10 \times (0.010 - 0.003) = 81$, 760 gal. Trucks...... 292, $000 \times 10 \times (0.021 - 0.004) = 49$, 640 gal.

The total annual fuel savings thus amount to 131,400 gallons. At 30 cents per gallon, this represents an annual savings of \$39,400.

Example B.—A grade-separation structure is planned at the interesection of a 4-lane divided parkway and a 2-lane crossroad where traffic signals now control vehicle movements. The average annual daily traffic volumes on the 4-lane and 2-lane routes are 20,000 and 4,000 vehicles per day, respectively. All vehicles on the parkway are passenger cars; 80 percent of those on the crossroad are passenger cars and 20 percent are 2-axle, singleunit trucks having an average gross weight of 10,000 pounds. The nominal highway speed on the parkway is 45 miles per hour and on the crossroad, 30 miles per hour. Turning movements at this intersection are so few in number that they may be neglected. It was determined from a study of traffic movements that on both routes traffic signals caused 25 percent of the vehicles to stop, with an average time loss while idling per stop per vehicle of 20 seconds or 0.33 minute. Compute the annual fuel and time savings which will result from this improvement.

Annual number of vehicles stopped on the crossroad at the intersection:

 $\begin{array}{lll} {\rm Passenger\; cars.} & 4,000 \times 80\% \times 365 \times 25\% = 292,000 \\ {\rm Trucks.} & 4,000 \times 26\% \times 365 \times 25\% = 73,000 \\ \end{array}$

From figure 4, unit fuel savings per stopand-go for passenger cars are 0.015 gal. at nominal speed of 45 m.p.h. and 0.009 gal. at 30 m.p.h.; for trucks, 0.017 gal. at 30 m.p.h. From figure 5, unit time savings per stopand-go for passenger cars are 0.21 min. at nominal speed of 45 m.p.h. and 0.14 min. at 30 m.p.h.; for trucks, 0.23 min. at 30 m.p.h. From table 2, fuel consumption while idling for passenger cars is 0.007 gal. per min.; for trucks, 0.011 gal. per min.

Annual fuel savings for passenger cars on the parkway:

Annual fuel savings for passenger cars on the crossroad:

Annual fuel savings for trucks on the crossroad:

The total annual fuel savings thus amount to 36,399 gallons. At 30 cents per gallon, this represents an annual savings of \$10,900.

Annual time savings for passenger cars on the crossroad: Annual time savings for trucks on the crossroad:

The total annual time savings thus amount to 1,163,620 minutes. Taking, for the sake of example, a value of 1½ cents per minute, the annual time savings are worth \$17,400. Thus the total annual fuel and time savings occasioned by construction of the grade-separation structure can be valued at \$28,300.

References

(1) NORMANN, O. K., GRANUM, J. O., Schwender, H. C.

New methods for determining capacity of rural roads in mountainous terrain. Public Roads, vol. 30, No. 2, June 1958; also Highway Research Board Bulletin 167, 1957.

(2) SAAL, CARL C.

Time and gasoline consumption in motor truck operation. Highway Research Board, Research Report No. 9-A, 1950.

(3) SAAL, CARL C.

Operating characteristics of a passenger car on selected routes. Public Roads, vol. 28, No. 9, Aug. 1955; also Highway Research Board Bulletin 107, 1955.

(4) SAWHILL, ROY B.

Motor transport fuel consumption rates. Highway Research Board paper, 39th Annual Meeting, Jan. 1960.

(5) Institute of Traffic Engineers

Traffic engineering handbook. 2d ed., New Haven, Conn., 1950.

(6) KENT, MALCOLM F.

Fuel and time consumption rates for trucks in freight service. See pp. 22-31 of this issue of Public Roads.

OADS

Fuel and Time Consumption Rates for Trucks in Freight Service

BY THE DIVISION OF TRAFFIC OPERATIONS BUREAU OF PUBLIC ROADS

> Reported ¹ by MALCOLM F. KENT, Transportation Economist

The number of times a truck must change its speed in a mile of travel increases with the density of traffic, according to an analysis of data derived from studies conducted in 1957 and 1958 of rural and urban travel in five States—data necessary in the analysis of highway-user benefits.

Using a congestion index, which indicates that speed changes per mile increase uniformly with average daily traffic for different types of highway, together with the rates of fuel and travel time consumed during a change in vehicle speed, the added cost of operating at nonuniform speed could be assessed.

This article also shows that, for the gross vehicle weights observed, smaller and less powerful engines give better fuel economy, but their use carries a penalty of increased time-consumption (lower road speeds) at the higher gross vehicle weights. Trucks with diesel engines were found to travel about 50 percent more miles on a gallon of fuel than trucks with gasoline engines of approximately equivalent power and gross weight characteristics.

NE of the greatest voids in the data avail-Oable for the analysis of highway-user benefits accruing through the improvement of highway facilities has been reliable fuel- and and time-consumption rates of commercial motor vehicles operating in actual service. To help fill this void the Bureau of Public Roads developed a program for obtaining this information. Ohio State University, the Universities of Michigan and Washington, and a transportation consultant from the University of Maryland were engaged to measure fuel consumption and overall travel time of selected trucks in rural and urban line-haul service and in city pickup and delivery service, under traffic conditions ranging from restricted to free flowing. This study group obtained the cooperation of private, government-owned, and for-hire highway freight carriers. Three of the studies were conducted simultaneously during the summer of 1957, and one during the summer of 1958.

A principal concern of highway planners of a few decades ago was the surfacing of dirt roads. Today, a principal concern is the elimination of frictional factors that impede the free flow of traffic on paved roads. Eliminating stops occasioned by stop signs and traffic lights, the widening of pavements or the adding of more lanes, the designing of highways with easier grades and curves, and the upgrading of other features that cause reduction in normal driving speeds, are factors that are now of primary importance.

In addition to improving the safety and efficiency of traffic flow, such improvements result in direct benefits to road users. Savings in motor fuel and time costs are two of the principal benefits that result, and they are directly affected by the elimination of frictional factors that impede the free flow of traffic. The over-all purpose of the studies described in this report was to provide data on fuel consumption and travel time for various vehicle types and traffic conditions, which could be used in the economic analyses of road-user benefits.

Summary of Findings

Major findings of the studies are summarized in the following paragraphs.

- 1. The fuel consumption in gallons per mile of motor trucks operating in rural and urban line-haul service increased with the power of the engine for equivalent gross vehicle weights.
- 2. Operating over identical rural line-haul routes, diesel-powered trucks were found to travel about 50 percent more miles on a gallon of fuel than gasoline-powered trucks of approximately equivalent power and gross vehicle weight. In terms of fuel consumption, this means that diesel-powered trucks consumed about 66 percent of the gallonage used by gasoline-powered trucks.
- 3. The consumption of gasoline per mile by trucks was 25 to 30 percent higher in urban areas than in rural areas.
- 4. The average truck speeds, including all stops and slowdowns, were found to be 37 miles per hour in rural line-haul operation, 19 miles per hour in urban line-haul operation, and 11 miles per hour in city pickup and delivery. For free-flowing traffic, the comparative speed for trucks in rural line-haul operation was 40 miles per hour.
- 5. The usefulness of speed changes per mile as a congestion index was demonstrated by proving that speed changes per mile increased uniformly with average daily traffic for differ-

ent types of highways. Knowing the number of speed changes saved, the proportion of stops and slowdowns, and the magnitude of each it is possible to use this index to compute the added cost of fuel and time caused by speed changes, when the extra fuel and time consumed during a speed change is known.

6. The stops on rural highways, made from the average truck speed, represented 11 percent of all deviations from desired speeds whereas the stops on urban streets represented 45 percent of all deviations from desired speeds.

7. The average number of speed change per mile was found to be 1.66 for rural line haul, 4.97 for urban line-haul, and 6.91 for city pickup and delivery operations.

Definition of Terms

To avoid misinterpretation of the results certain terms used in this article are defined

Fuel consumption.—Gallons of gasoline of diesel fuel consumed per mile of highway travel. The conversion from gallons per mile to miles per gallon can easily be made sine one is the reciprocal of the other.

Travel time.—Minutes required to trave origing 1 mile. Minutes per mile can be converted and to miles per hour by dividing 60 by the minutes per mile.

Stop.—Bringing a motor vehicle to complete stop.

Slowdown.—A reduction in speed of a motor pality vehicle of more than 3 miles per hour without inecoming to a stop.

Speed change.—All motor vehicle accelerations and decelerations effecting a spee deliverance of more than 3 miles per hour, including C both stops and slowdowns.

Average gross vehicle weight.—The average of the individual gross vehicle weights on several vehicles, all falling within the same deliverage class interval of gross vehicle weight.

Engine cubic-inch displacement.—The crossing of sectional area of a cylinder multiplied by the from length of piston stroke, which gives the native cylinder displacement; multiplied by the ware number of cylinders.

Net horsepower.—The brake horsepower of that the engine, operating with all its normal accessories, that is available at the clutch of ind its equivalent. It is the gross horsepower minus the horsepower absorbed by far mate compressor, generator, etc. For all practics and

¹ This article was presented at the 39th annual meeting of the Highway Research Board, Washington, D.C., January

Table 1.-Route termini, route numbers, distances, and rates of rise and fall of rural highways traveled by observed line-haul trucks

Ter	mini	Numbered routes	Mileage 1	Rate of
From	То			fall 2
Washington, D.C	Baltimore, Md	Md. 193, U.S. 1	32.6	1.58
Do	Richmond, Va	Va. 350, U.S. 1		1.42
Columbus, Ohio	Cleveland, Ohio	Ohio 3, 61, U.S. 42	128. 4	1.41
Do	Parkersburg, W. Va	U.S. 33, 50	108.8	. 63
Do	Wheeling, W. Va	U.S. 40	119.9	1.70
Detroit, Mich	Lansing, Mich.	U.S. 16	80. 5	. 59
Do	Toledo, Ohio	U.S. 25	55. 4	. 16
Do		U.S. 112, 12, Mich.60	151.7	. 48
Seattle, Wash	Aberdeen, Wash	U.S. 99, 410	95. 5	1.25
Do	Bellingham, Wash	U.S. 99	75. 5	1.28
Do	Centralia, Wash	U.S. 99	74.7	1.09
Do	Chehalis, Wash	U.S. 99	80.7	1.09
Do	Everett, Wash	U.S. 99	18.5	1.87
Do	Longview, Wash	U.S. 99, 830	120.7	. 95
Do	Mt. Vernon, Wash	U.S. 99	53. 9	1. 24
Do		U.S. 99	53. 1	1.29
Do	Portland, Oreg	U.S. 99	161.2	. 93
Do	Tacoma, Wash	U.S. 99	23. 9	1.59
Do	Yakima, Wash	U.S. 10, 97	139. 1	1.35

Between municipal boundaries of terminal cities.
 In feet per 100 feet of distance.

nist

tops ach. the

peed time

n.

from

per-

eeds

fined

ne o

hwat

mil

its 0

purposes, net horsepower is assumed to be 90 percent of the gross horsepower.

Total rise and fall.—The arithmetic sum of the vertical rise and fall in feet for any section of highway. The rise in one direction of nted travel will become the fall in the opposite sired direction. The total rise and fall is the same regardless of the direction of travel.

Rate of rise and fall.—The total rise and fall line for any section of highway in feet divided by for the length of section in hundreds of feet. It is not to be confused with the percent of grade. It is equivalent to the average percent of grade only when either the rise or fall is 100 sults percent of the total rise and fall.

Description of Test Routes

The four studies were conducted in the general areas of Maryland-District of Columsine bia-Virginia, Ohio, Michigan, and Washington. The line-haul (intercity) routes with their rave origins, destinations, route numbers, mileages, erter and rates of rise and fall are shown in table 1. the The urban extensions of the line-haul routes in Cleveland and Columbus, Ohio, Detroit, to Mich., Baltimore, Md., Washington, D.C., Seattle, Wash., and some smaller municimoto palities were studied separately from rural thou line-haul operation. These generally followed the numbered routes until diversion was elers becessary to reach the trucking terminal or spee delivery warehouse.

luding City pickup and delivery service was studied in Detroit, Columbus, Seattle, and verag Washington, D.C. All such operations were on irregular routes except for the postal sam delivery service trucks which followed the same routes each day to the various substations cross in Columbus. The types of service varied by the from large tractor-truck semitrailer combis the nations delivering grocery products from y the varehouses to retail stores and motor fuel from wholesale storage tanks to retail filling wer a stations, to panel and van-type trucks engaged norms in package or linen delivery service. Rise tch of and fall rates were estimated for Columbus, power Detroit, and Washington, D.C., at approxifan mately 0.5 foot per 100 feet. Rates of rise actics and fall for routes were recorded for Seattle,

and ranged from 1.9 to 2.3 feet per 100 feet. However, the variations in rates of rise and fall among routes were not of sufficient magnitude to cause significant changes in fuel and time consumption.

Description of Test Vehicles

The gasoline- and diesel-powered tractortruck semitrailer combinations, made available by commercial carriers for line-haul observation, are described in table 2 according to type, engine displacement, and net brake horsepower. City pickup and delivery gasolinepowered vehicles, consisting of panel and other single-unit trucks and tractor-truck semitrailer van and tank combinations, are similarly described in table 2.

Where the size and weight restrictions of the particular State permitted, three vehicles were observed in each State within each of the following weight groups:

Rural and urban line-haul (pounds)	City pickup and delivery (pounds)
20,000-29,999	5,000- 9,999
30,000-39,999	10,000-19,999
40,000-49,999	20,000-29,999
50,000-59,999	Over 30,000
60.000-69.999	

Test Procedures

After receiving permission from fleet owners to use their vehicles for test purposes, in the course of their normal runs, a fuel meter was placed in the cab of each gasoline-powered truck and connected to the fuel lines of the engine between the tank and the carburetor. The fuel meter could be read by a person sitting next to the driver. The fuel tank was filled at the start of each trip and was filled again at the end of the trip; any fuel added enroute was, of course, recorded. This overall record of fuel consumption was used to check the accuracy of the meters.

Diesel-engine trucks, in which excess fuel is recirculated from the engine to the fuel tank, required a different type of meter installation. To circumvent the multimetering of the same fuel, a small-volume, constant-level tank was

Table 2.—Characteristics of commercial motor vehicles made available for study

Number of vehicles	Number of axles and body types ¹	Engine cu. in. dis- place- ment	Net brake h.p. of engine ²	Engine r.p.m.
Line-haul,				
1	3-S2-2 van.	302	172	3,600
3	3-S2 van	331	128	3, 200
1	2-S2 van		126	2,800
12	2-S1 van		130	2,800
8	3-Si van		156	2, 750
4	3-S2 van.	450	146	2, 600
2	3-82 van	461	197	3, 200
3	2-S2 van	501	165	2,800
1	3-2 van	531	178	2,880
1	3-S2 van	549	230	3, 200
4	3-S2 van	590	225	2,800
Line-haul, diesel:				
5	3-S2 van	743	200	2, 100
City pickup and de- livery,				
gasoline:	2 panel	214	73	3, 200
1	do		126	4,000
1	do.	235	123	4,000
1		220	89	2, 800
5	do	228	90	3,000
5			115	3, 400
	do		90	2, 500
	do		135	4,000
1			105	3, 400
3	do	271	114	2, 800
2			167	4, 400
1			103	3, 200
2	do	. 320	103	3,000
1	do	. 386	163	3,000
2	2-S1 van	372	139	3, 200
2	do	. 386	145	3,000
3	do		175	3, 200
1		383	150	2, 800
2	do		150	2,800
1		505	175	2,800
2	2-S2 tank	464	170	2,800

¹ Each digit indicates the number of axles of a vehicle or of a unit of a vehicle combination. A single digit, or the first digit of a group symbol, represents a single-unit truck or, if followed by an S, represents a truck-tractor. The S designation represents a semitrailer. A digit, without an S preceding it, in the second or third position of a group symbol represents a full trailer.

² Average 140 horsepower for engine sizes 302-406 cu. in., average 171 horsepower for sizes 450-549.

installed in the fuel line between the engine and the main fuel supply tank. The engine fuel pump drew only from this feed tank, to which all excess recirculated fuel was returned. Fuel consumed by the engine was drawn from the feed tank, and a constant level was maintained in the feed tank through a float arrangement and an auxiliary fuel pump supplying additional fuel from the main supply tank through a fuel meter unit. In this manner, the fuel meter recorded only the

actual quantity of fuel consumed by the

engine.

Before the beginning of the test runs each route to be observed was inventoried to locate control points with relation to major changes in traffic flow and to record mileage between control points, rise and fall (through use of an aneroid barometer), number of traffic signs and signals, and number of lanes. Before the start of each run, the observer recorded the vehicle chassis model and year, unladen weight, payload weight, and gross vehicle weight, engine model size and cubic inches of cylinder displacement, and reported net brake horsepower. The weather and condition of the road were also recorded.

The observer, riding in the cab, recorded on each run the following information as he passed the control points: time of day (hour

and minute), fuel meter reading (hundredths of a gallon), and odometer reading (tenths of a mile). The magnitude of each speed change of plus or minus 3 miles per hour or more within each section was recorded during the trip. Trips were made at all hours of the day and night, with no change from normal operations being made on account of the study. Drivers were not to change their normal driving habits, and drove at speeds representative of other traffic.

Analysis Procedures

When the fieldwork had been completed, the first step in the analysis procedure was to list the consumption of fuel, travel time, and mileages traveled on each section for each trip, segregating rural from urban data. Speed changes were similarly listed for each section and trip, with stops being shown separately from slowdowns in the Ohio and

Washington data. Gallons per mile, minutes per mile, and speed changes per mile were computed separately for line-haul rural trips, for line-haul urban trips, and for city pickup and delivery trips.

Rate of rise and fall

Rise and fall was considered a variable with respect to fuel consumption rates and travel time. No significant variations were found, however, in either parameter for the rather narrow range of rates of rise and fall studied. As shown in table 1, rates of rise and fall for the rural highways studied ranged from 0.16 for the route between Detroit and Toledo, to 1.87 for the route between Seattle and Everett. Of the total mileage studied, 40.6 percent had a rate of rise and fall below 1.0, 47.7 percent had rates from 1.0 to 1.5, and 11.7 percent had rates from 1.51 to 1.87. The average rate of rise and fall for all rural sections studied was 1.22. The results reported for this study

Table 3.-Number of trips and total miles observed for gasolineand diesel-powered motor vehicles, classified by gross vehicle weights

	Average	Gasoline veh	powered icles	Diesel-p veh	oowered icles
Weight classes (pounds)	vehicle weight	Number of trips	Total miles observed	Number of trips	Total miles observed
Line-haul vehicles:					
17,000-18,999	17,000	15	1, 111		
19,000-23,999	21, 300	55	3, 085		
24,000-29,999	27,000	25	2,398	1	60
30,000-37,999	34, 500	123	11,740	6	545
38,000-47,999	42,000	98	8, 906	12	1, 641
48,000-53,999	51, 200	64	5, 381	8	668
54,000-61,999	59, 500	42	3, 520	9	1, 125
62,000 and over	67, 900	31	2, 111	12	1, 503
Total		453	38, 252	48	5, 542
City pickup and delivery vehicles:					
4,400-4,999	4,600	13	231		
5,000-8,999	6,000	25	1, 172		
9,000-12,999	10, 500	89	1,775		
13,000-16,999	14, 500	51	603		*****
17,000-20,999	18, 500	6	67		
21,000-24,999	22, 500	1	33		
25,000-30,499	27, 500	80	480		
30,500-36,999	33, 300	18	232		
37,000-39,999	38, 500	3	81		
40,000-45,999	42, 100	5	171		
51,000-51,999	51, 300	3	154	******	
54,000-59,999	57,000	40	64		
62,000-69,999	66, 000	32	70		
Total		366	5, 133		

Table 4.—Summary of fuel-consumption rates for line-haul trucks operating over rural highway, classified by gross vehicle weights and engine power

	Fuel-co	nsumption ra	ates in ga	llons per mile	of or vehi	cles with eng	ine displ	acement of-
Gross vehicle weight (pounds)	302–406 cu. in. gasoline-powered (140 hp.)		450–549 cu. in. gasoline-powered (171 hp.)		gasolir	cu. in. ne-powered 25 hp.)	743 cu. in. diesel-powered (200 hp.)	
	Actual rate	Computed rate 2	Actual rate	Computed rate 3	Actual rate	Computed rate 3	Actual rate	Computed rate 2
17,000	0. 150	0. 154	0.152	0.173				
21,300	. 163	. 163	. 189	. 185				
27,000	. 170	. 175	. 210	. 200	0. 243	0. 241	0.146	0.153
34,500	. 196	. 191	. 229	, 219	. 247	. 253	. 176	. 162
42,000	. 214	. 207	. 246	. 239	. 278	. 266	. 176	. 171
51,200	. 233	, 226	. 256	. 263	. 273	. 280	. 164	. 182
59,500	. 233	. 244	. 289	. 285	. 287	. 294	. 189	. 193
67,900			. 298	. 307	. 314	. 307	. 212	. 203

 1 Average rate of rise and fall, 1.2 feet per 100 feet, 2 Computed rates are based on the following formulas: 302–406 cu. in., 0.1177+0.00212W; 450–549 cu. in., 0.1288+0.00262W; 590 cu. in., 0.1975+0.00162W; and 743 cu. in., 0.1194+0.001229W. (W=GVW in thousands the control of the co

reflect the average values for all highway sections without regard to variations in rise and fall.

Vehicle weight groupings

It was not possible to set up a precise schedule of vehicles and gross vehicle weights to be observed, since the demand for commercial freight in normal operations did not permit the selection of a specified gross vehicle weight. It was hoped that the plan to observe a minimum of three vehicles for each of several weight-class intervals would result in an even distribution within the class interval. This, however, was not the case and it was necessary to form new gross vehicle weight groupings in the analyses. The most significant groupings for the line-haul and pickup and delivery vehicles, together with the number of trips and total miles observed in each grouping, are shown in table 3. It is evident that sizable mileages were logged in each type of service and that a reliable base exists for the development of fuel consumption and travel time rates.

Engine size groupings

The gasoline-powered vehicles observed on line-haul operations were grouped, for purposes of analyses, into three engine displacement size groups consisting of 302-406 cubic inches, 450-549 cubic inches, and 590 cubic inches. Vehicles with 743-cubic-inch displacement diesel engines were also studied as a group. The net horsepower for the four groups of engine displacement were determined to be 140 horsepower for the 302-406-cubic-inch size group, 171 horsepower for the 450-549-cubic-inch size group, 225 horsepower for the 590-cubic-inch size group, and 200 for the 743-cubic-inch diesel engine.

A grouping of city pickup and delivery vehicles by power characteristics was considered but found impractical for the purposes of analysis because of the irregularity of the service, which resulted in wide variations in the speed of operation, number of deliveries, stops per mile, idling time, and the rate of discharge of cargo.

gro

we tio

cor

vel rep

0.2 lar

per

tion

& .25

Fi.

1

PU

Average Fuel Consumption Rates

A summary of the average rates of fuel consumption is shown in table 4. Two fuel consumption values are shown for each group of vehicles with similar power characteristics. One is the actual rate and the other is the computed rate, shown in figure 1 as straight line relationships, which were derived from the actual average values. The rates of rise and fall were 1.18 feet per 100 feet for the 302-406-cubic-inch group, 1.20 feet per 100 feet for the 450-549-cubic-inch group, 1.29 feet per 100 feet for the 590-cubic-inch group. and 1.22 feet per 100 feet for the 743-cubicinch diesel engine. The variation in rise and fall appeared to be rather insignificant and therefore a valid comparison of the motor-fuel consumption rates for the several groupings of vehicles is practical.

It may be noted that the vehicles with the larger power plants used appreciably more gasoline for a given average weight. For

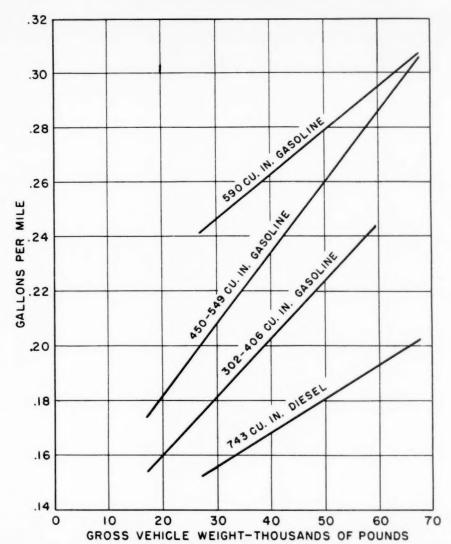


Figure 1.-Motor-fuel consumption rates of rural line-haul trucks by size of engine for 1.2 rate of rise and fall.

instance, in figure 1 it is seen that gasolinepowered vehicles in the lowest engine power group with an average GVW (gross vehicle weight) of 40,000 pounds had a fuel-consumption rate of 0.202 gallon per mile. This compares with 0.233 gallon per mile for vehicles in the medium power group, which represents a 15-percent increase; and with 0.262 gallon per mile for vehicles in the largest gasoline-engine power group, a 30percent increase.

98

ts

r-

r-

le

b-

of

in

al.

ht

fi-

up

he

in

is

in

p-

on

ur-

bie

bie

lis-

ied

the

ere

3'er

225

up,

ne.

erv

on-

ses

the

in

ies.

of.

S

fuel

fuel

oup

ties. the ight rom

rise

the

100 1.29

oup.

bicand and fuel

ings

the

ore

Fo

ADS

Also, it may be seen that the fuel-consumption rate increased with gross vehicle weight.

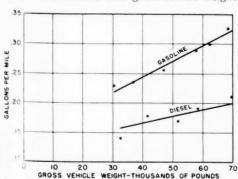


Figure 2.—Comparison of gasoline and diesel fuel consumption rates of rural line-haul trucks operating over the same Tilltee

PUBLIC ROADS . Vol. 31, No. 1

In the medium power group, for instance, a vehicle weighing 20,000 pounds consumed approximately 0.181 gallon per mile, while a vehicle weighing 60,000 pounds consumed 0.285 gallon per mile. However, despite the fuel-consumption rate increase with gross vehicle weight increase, there was a decrease in the fuel consumption per 10,000 pounds of gross vehicle weight. For example, in

the medium power group a 20,000-pound vehicle consumed 0.181 gallon per mile, or 0.091 gallon per mile per 10,000 pounds, while a vehicle weighing 60,000 pounds which consumed 0.285 gallon per mile actually consumed only 0,048 gallon per mile per 10,000 pounds, indicating that as gross vehicle weight is increased the fuel economy per unit of gross weight is improved.

Gasoline and diesel fuel comparison

For the same gross vehicle weight averages, the diesel-powered vehicles consumed considerably less fuel than the gasoline-powered vehicles with approximately the same power characteristics. For example, a vehicle with a 590-cubic-inch gasoline engine and an average GVW of 60,000 pounds consumed approximately 0.294 gallon per mile, while a vehicle with a 743-cubic-inch diesel engine and a similar weight consumed 0.193 gallon per mile. In this case the diesel consumption rate was 66 percent of the gasoline consumption rate. However, the foregoing comparison does not represent results obtained over identical routes.

A comparison of gasoline and diesel fuel consumption rates for vehicles traveling over identical routes was possible from the data obtained in the State of Washington. diesel-powered combination units traveled a total of 5,542 miles on 48 trips. Twentyeight of these trips, totaling a distance of 3,617 miles, were traveled over the same routes used by gasoline-powered trucks on 32 trips, totaling 3,966 miles. By grouping gross vehicle weights into class intervals, it was possible to obtain average consumption values that were directly comparable with respect to rise and fall rates and gross vehicle weight. Of the vehicles with gasoline engines, 21 trips were made by vehicles with engines of 461-cubicinch displacement, 3 with engines of 450cubic-inch displacement, and 8 with engines of 590-cubic-inch displacement. For the 32 trips, the average net horsepower of the vehicles with gasoline engines was 199 horsepower, as compared with the 200-horsepower diesel engines. The results are summarized in table 5 and the relationships derived from the average rates of fuel consumption are shown in figure 2.

Table 5.—Gasoline and diesel fuel consumption rates for line-haul trucks traveling over the same rural routes, classified by gross vehicle weights 1

Gross vehicle weight (pounds)	Number of trips	Total miles traveled	Total gallons con- sumed	Actual rate, miles per gallon	Computed ² rate, miles per gallon		Computed rate, gallons per mile
Gasoline:							
30,400	1	63	14. 34	4. 393	4. 452	0. 228	0. 221
36,800	2	284	66.77	4. 253	4, 224	. 235	. 237
46,800	7	993	254, 89	3.896	3, 867	. 257	. 263
57,900	14	1,831	529. 23	3.460	3.472	. 289	. 292
62,500	1	142	42. 45	3. 345	3.308	. 299	. 303
68,300 Total or	7	653	213. 25	3.062	3. 101	. 327	. 318
Diesel: average	32	3, 966	1, 120. 93	3, 538		. 283	
32,600	1	65	9, 15	7, 104	6, 723	0.141	0.158
41,500	7	923	163, 89	5, 632	6, 229	. 178	. 168
51,600	6	618	105, 17	5, 876	5, 668	. 170	. 179
58,100	8	1, 146	219. 87	5, 212	5, 306	. 192	. 187
69,900 Total or	6	865	182. 15	4.749	4, 651	. 211	. 200
average	28	3, 617	680, 23	5. 317		. 188	

¹ Average rate of rise and fall, 1.17 feet per 100 feet. ² Computed miles-per-gallon rates are based on the following formulas: gasoline, 5.53486-0.03563W; diesel, 8.5345-0.05556W.

8.5345-0.05556W.

2 Computed gallons-per-mile rates are based on the following formulas: gasoline, 0.14217+0.00258W dlesel, 0.12106+0.00113W. (W=GVW in thousands of pounds.)

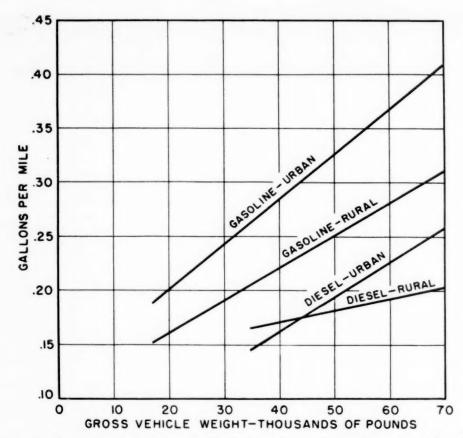


Figure 3.—Comparison of rural and urban motor-fuel consumption rates of line-haul trucks.

For a GVW of 70,000 pounds, as shown in figure 2, the gasoline consumption rate was 0.322 gallon per mile, or 3.11 miles per gallon; and the diesel consumption rate was 0.200 gallon per mile, or 5.00 miles per gallon. In effect the diesel-powered vehicles traveled about 53 percent more miles per gallon of fuel than did the gasoline-powered vehicles. A similar comparison for a GVW of 50,000 pounds indicated that the diesel-powered vehicles traveled about 52 percent more miles per gallon of fuel than gasoline-powered vehicles. A comparison of the average rate for all gasoline-powered vehicles for all 32 trips with that for all diesel-powered trips shows that 51 percent more mileage was obtained by diesel-powered vehicles on the same gallonage of fuel. This relative value is based on the total miles traveled and total gallons consumed shown in table 5. The average diesel consumption rate of 0.188 gallon per mile was 66 percent of the average gasoline consumption rate of 0.283 (also shown in fig. 1).

Rural and urban comparison

The fuel consumption rates for all gasolineand diesel-powered trucks observed in linehaul rural and urban travel are shown in table 6. The computed rates, obtained from the straight-line relationships shown in figure 3, were derived from the average actual rates. Referring to figure 3, the fuel consumption rates for gasoline-powered vehicles in urban travel appear to be considerably greater than the gasoline consumption rates in rural travel. The fuel consumption percentage differences in rural and urban travel range from a 25percent difference for a GVW of 20,000 pounds to a 32-percent difference for a GVW of 70,000 pounds.

A comparison of the rural and urban fuel consumption rates for diesel-powered trucks observed in line-haul service, however, shows that there was little percentage difference where the GVW was from 40,000 to 50,000 pounds, but where the GVW approached 70,000 pounds there was a 27-percent higher consumption rate in urban travel.

Again, figure 3 shows the fuel consumption advantage of the diesel engine.

City pickup and delivery vehicles

City pickup and delivery motor-vehicle gasoline consumption rates are shown in figure 4 for two different rates of rise and fall. The straight-line values were derived from actual average values. In Seattle, where the rate of rise and fall averaged 2.1 feet per 100 feet, the gasoline consumption was 18 percent higher at 10,000 pounds GVW and 14 percent higher at 40,000 pounds GVW than the consumption rate in the other three cities where the rise and fall was about 0.5 feet per 100 feet. It will be noted that gasoline consumption increased as gross vehicle weights increased, as was the case for line-haul operation. It may also be noted that the consumption rates approximate very closely the values shown in figure 3 for gasoline-powered vehicles in urban line-haul service. Consumption rates for

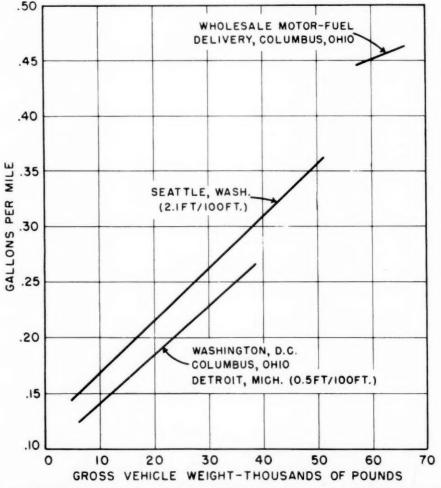


Figure 4.—Motor-fuel consumption rates at different rates of rise and fall for city delivery vehicles.

sh

Table 6.—Gasoline and diesel fuel consumption rates for rural and urban line-haul operations, classified by gross vehicle weights

		Gasoline	and diese	el fuel consur	nption ra	ites in gallon	s per mil	e		
Gross vehicle		Gasoline-pow	ered veh	nicles		Diesel-powered vehicles				
weight (pounds)	Rur	al travel	Urba	an travel	Rur	al travel	Urba	an travel		
	Actual rate	Computed rate 1	Actual rate	Computed rate 1	Actual rate	Computed rate ¹	Actual rate	Computed rate 1		
17,000 21,300 27,000 34,500	0. 150 . 166 . 184 . 206	0. 152 . 165 . 182 . 204	0. 175 . 218 . 232 . 263	0. 189 . 207 . 230 . 261	0. 176	0. 167	0. 147	0. 146		
42,000	. 229 . 243 . 280 . 308	. 227 . 254 . 279 . 304	. 291 . 332 . 365 . 395	. 292 . 330 . 364 . 399	. 176 . 164 . 189 . 212	. 174 . 184 . 192 . 200	. 179 . 180 . 225 . 255	. 169 . 198 . 224 . 250		

 $^{^{1}}$ Computed rates are based on the following formulas: gasoline, rural, 0.10115+0.00299W; gasoline, urban, 0.11865+0.00413W; diesel, rural, 0.13180+0.00101W; diesel, urban, 0.03924+0.00310W. (W=GVW in thousands of pounds.)

Table 7.—Comparison of motor-fuel consumption rates of three studies of trucks operating over rural highways,¹ classified by gross vehicle weights

	1	Motor-fu	el consui	mption in	zallons per	mile from in	dicated str	idies
Average gross		1958	five-Sta	te study		1937 Oreg	1948 Penn sylvania study	
vehicle weight (pounds)	Gas	oline-pov	wered ve	hicles				
		cubic in cement o		Average	Diesel- powered vehicles	Gasoline- powered vehicles	ered powered	Gasoline- powered vehicles
	302-406	450-549	590					
20,000 30,000 40,000	. 202	0. 181 . 207 . 234	0. 246 . 262	0. 161 . 191 . 221	0. 156 . 169	0. 203 . 251	0. 128 . 157	0. 135 . 170 . 200
50,000	. 224	. 260 . 286 . 312	. 279 . 295 . 311	. 251 . 281 . 311	. 181 . 193 . 205	. 295	. 183	. 228 . 255 . 282

Rate of rise and fall for Oregon data was 1.0; for the other study data it was 1.2.

wholesale motor-fuel delivery vehicles are shown separately in figure 4 as they were not considered for this study as multi-stop city delivery vehicles.

Comparison with previous studies

00

W

10

d

m

ele

in

11.

m

he

nt

11-

re

on

ed,

It

in

Fuel-consumption rates obtained in this study have been compared with results found in two previous studies—a 1937 Oregon study (1), and a 1948 Pennsylvania study (2).² The

comparison of these consumption rates are given in table 7 and illustrated graphically in figure 5. For comparative purposes, the average consumption rates found in the 1958 study, rather than the rates found for the individual groupings of vehicles, were used. Considering the entire gross vehicle weight range, the consumption rates obtained in the

1958 study were found to be approximately 10 percent higher than corresponding data reported in the Pennsylvania study, which were obtained by controlled tests on new vehicles. The higher motor-fuel consumption rates in commercial operation as compared with the controlled test operation can be ascribed partly to a greater prevalence of speed changes in commercial operation than had been encountered in the test truck operation, and partly to the fact that the commercial truck engines were not kept to the high degree of performance efficiency as the controlled test trucks, which were regularly maintained by factory mechanics.

It appears that the results in the Pennsylvania study, which covered a much wider range of gross vehicle weights and rates of rise and fall, may be increased by 10 percent and used to represent the fuel characteristics of vehicles now in actual commercial service.

Gasoline consumption rates in the 1937 Oregon study and the 1958 study were quite similar in the lower gross vehicle weights but the Oregon study gasoline consumption rates were higher by nearly 20 percent for the gross vehicle weights at 50,000 pounds. Diesel-fuel consumption figures in the Oregon study were lower than the 1958 study diesel consumption rates by as much as 30 percent in the lower weight ranges but were almost identical for gross vehicle weights at 50,000 pounds.

Average Time Consumption Rates

The travel time consumption rate of commercial motortrucks in rural line-haul operation was analyzed in two different ways. The first analysis was made to determine the travel time of vehicles for all trips, without considering rise and fall or traffic friction. This analysis was made in a manner similar to that used for determining the fuel-consumption rates. Actual and computed travel time consumption rates are given in table 8. In figure 6, straight lines are used to relate travel time and gross vehicle weight for each of the engine characteristic groups. It is seen that vehicles with engine displacement size of 302-406 cubic inches, which traveled

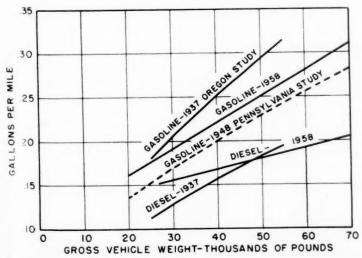


Figure 5.—Comparison of data from 3 reports on motor-fuel consumption rates of line-haul trucks.

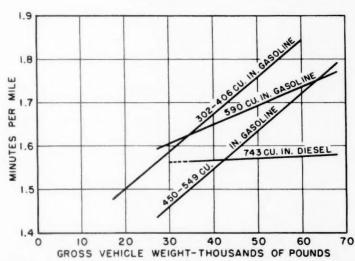


Figure 6.—Comparison of average time consumption rates of rural line-haul trucks by engine size for 1.2 rise and fall.

 $^{^{2}}$ Italic numbers in parentheses refer to the list of references on p. 31.

Table 8.-Rates of travel time consumption for trucks in rural line-haul service in 5 States, 1957-58

	Trav	el time-consu	mption ra	tes in minutes	s per mile	for vehicles v	with engine	displacen	nent of—
Gross vehicle weight (pounds)				590 cu. in., gasoline (225 h.p.) engine			in., diesel p.) engine		
	Actual rate	Computed rate 2	Actual rate	Computed rate 2	Actual rate	Computed rate 3	Actual rate	Actual rate	Computed rate 2
17,000 21,300	1. 434 1. 506	1. 478 1. 514	*****			******	1. 434 1. 506	*****	*******
27,000 34,500	1. 649 1. 619	1. 563 1. 627	1. 467 1. 520	1. 436 1. 501	1. 606 1. 590	1, 593 1, 626	1. 592 1. 596	1. 636	1. 567
42,000 51,200	1. 687 1. 728	1.691 1.769	1. 526 1. 626	1, 566 1, 645	1.662 1.738	1. 659 1. 699	1, 620 1, 692	1. 460 1. 616	1. 571 1. 576
59,500 67,900	1. 859	1, 840	1, 660 1, 859	1. 717 1. 790	1. 724 1. 761	1. 735 1. 771	1, 696 1, 797	1. 569 1. 598	1. 580 1. 585
Average	1. 638	*******	1. 586		1.696		1, 625	1, 559	

¹ Average rate of rise and fall, 1.2 feet per 100 feet. ² Computed rates are based on the following formulas: 302–406 cu. in., 1.333+0.008516W; 450–549 cu. in., 1.203+0.008642W; 500 cu. in., 1.476+0.004347W; and 743 cu. in., 1.549+0.000526W.

Table 9.—Summary of travel time consumption rates, by gross vehicle weights and power characteristics, for urban line-haul freight vehicles and city delivery vehicles

Time-consumpt vel	ion rates i nicles with	n minutes engine dis	per mile fo placement	r urban lin of—	e-haul	Time consumption rates minutes per mile for c delivery vehicles		
Gross vehicle weight (pounds)	302-406 cu. in., gasoline engine	450-549 cu. in., gasoline engine	590 cu. in., gasoline engine	Average gasoline engine	743 cu. in., diesel engine	Gross vehicle weight (pounds)	All gasoline engines	
17,000	3. 207	2.868		3. 105		4,600	8. 854	
21,300	2. 909 3. 388	3. 473 2. 818	2.957	2. 987 3. 182	2, 556	6,000	5. 736 6. 181	
34,500	3. 260	2. 973	2. 378	3. 136	2. 353	14,500	5. 125	
42,000	3. 274	3.082	2.728	3. 167	2. 597	18,500	4. 500	
51,200	3.513	2.914	2. 283	3. 253	2.901	22,500	5. 502	
59,500	4. 533	2. 987	2. 532	3. 435	3.043	27,500	4.847	
67,900	4. 486	2.630	2.815	3. 039	2.784	33,300	4. 184	
Average	3. 306	2, 997	2, 671	3. 156	2,740	Average	5. 443	

at a rate of 1.59 minutes per mile with a GVW of 30,000 pounds, traveled at 1.85 minutes per mile when the GVW was 60,000 pounds. Vehicles in the 450-549-cubic-inch engine size group traveled 1.46 and 1.72 minutes per mile at corresponding weights. The straight-line relationships for these two engine groups were approximately parallel, indicating a constant rate of increase in travel time consumed with increase in gross vehicle weights.

The vehicles with 743-cubic-inch diesel engines maintained a much more constant

speed with respect to gross vehicle weights than those with the larger gasoline engines, showing an increase of only 0.02 minute per mile from 30,000 to 60,000 pound GVW.

The travel time consumption rates of commercial vehicles in urban line-haul and in city pickup and delivery service are shown in table 9. Although time-consumption rates were not found to vary in a uniform manner with gross vehicle weight, it was noted that as the power characteristics of engines increased the time consumption decreased.

Table 10.—Average speeds of gasoline- and diesel-powered trucks, experiencing less than two slowdowns per mile and no stops in Ohio and Washington rural line-haul operation

	Time-consumption rates ²											
21,300		i, in, gaso- ngine		ı. in, gaso- ngine	590 cu. in. gasoline engine		743 cu. in. diesel engine					
	Minutes per mile	Miles per hour	Minutes per mile	Miles per hour	Minutes per mile	Miles per hour	Minutes per mile	Miles per hour				
17,000	1. 34 1. 38 1. 43 1. 50	44. 8 43. 5 42. 0 40. 0	1. 35 1. 40	44. 4 42. 9	1. 36 1. 38	44. 1 43. 5	1. 483	40. 5				
42,000	1. 57 1. 65	38. 2 36. 4	1. 44 1. 50 1. 56 1. 61	41. 7 40. 0 38. 5 37. 3	1. 40 1. 43 1. 45 1. 47	42. 9 42. 0 41. 4. 40. 8	1. 486 1. 490 1. 493 1. 497	40. 4 40. 3 40. 2 40. 1				

verage rate of rise and fall, 1.3 feet per 100 feet.

Rates were computed by the following formulas. 302-406 cu. in.: m.p.m., 1.18035+0.00916W; m.p.h.,

186-0.25747W.

0-0.23/47 W. 450-549 cu. in.; m.p.m., 1.17435+0.00643 W; m.p.h., 49.2757-0.17956 W. 590 cu. in.; m.p.m., 1.2909+0.00264 W; m.p.h., 46.0567-0.07742 W. 743 cu. in.; m.p.m., 1.4696+0.00040 W; m.p.h., 41.1719-0.01905 W. (W=GVW in thousands of pounds.)

Referring to the average time-consumption rates for all gasoline-powered vehicles (tables 8 and 9) it will be seen that vehicles in rural line-haul service traveled at an average rate of 1.625 minutes per mile, or 36.9 miles per hour; vehicles in urban line haul traveled at 3.156 minutes per mile or 19.0 miles per hour; and all city pickup and delivery vehicles at 5.443 minutes per mile or 11.0 miles per hour. Similar figures for diesel-powered vehicles were 1.559 minutes per mile, or 38.5 miles per hour for rural line-haul operation, and 2.740 minutes per mile, or 21.9 miles per hour for urban line-haul operation.

Tim

date

COLL

sylv

rate

stud

all v

a 1.5

Fig

ti

p

24

0

1

195

tim

"av

be :

rep

par

be i

figu

194

ma

con

tra

cen

in t

to

vol

vel

goo

ane

sta

cer

ho

an

tin

av

va

cos

str sid for of We ch slo ma

ha spe Sp

res

We

gre

ru

PU

Average speeds in free-flowing traffic

The second analysis made of travel time for rural line-haul operations involved the desired speeds at which vehicles traveled in free-flowing traffic when they apparently were unrestricted except by speed limits or safe driving speeds. It was possible to study the speeds by analyzing time-consumption rates on certain highway sections in Ohio and Washington where trucks traveled without experiencing more than two slowdowns per mile and no stops. The average operating speeds under these conditions were related to the four groupings of engine sizes and power characteristics and to gross vehicle weight, as shown in table 10 and figure 7.

Travel time, in minutes per mile, increased sharply as the gross weight of gasoline-powered commercial trucks in the lowest range of engine size and power increased. Conversely, of course, average road speeds decreased sharply. However, as the engine horsepower and gross vehicle weight increased, the travel time increase was less pronounced. This is reflected by the steepness of the slope of the lines per 10,000-pound increase in GVW. For the lowest gasoline-powered engine size, the rate increased 0.09 minute per mile for each increase of 10,000 pounds in GVW. For the medium gasoline-powered engine size, the corresponding increase was 0.06 minute per mile, and for the 590-cubic-inch engine gasolinepowered vehicles and the diesel-powered vehicles the increases were 0.03 and 0.01 minute per mile, respectively.

The relative performance of the four groupings of vehicles (fig. 7) point up the consideration that while better fuel economy is attained with smaller engines for the gross vehicle weights investigated, the penalty of using smaller engines is an increase in travel time consumption at higher vehicle weights.

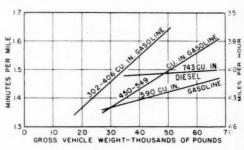


Figure 7.—Average time consumption rates for trucks operating in free-flowing traffic on rural line-haul service with an average rate of rise and fall of 1.3 feet per 100 feet.

Time-consumption rates compared

8 al

e

r

d

er

38

er

d

.5

n,

e-

1e

h-

i-

d

ıır

in

ed

ed

of

ed

er

el

or

he

ch

he

le.

6-

te

p-

ed

ele

ng

PERO

MILES

es

fic

20

t.

15

Another important use of the current study data was in comparison with the average time-consumption rates reported in the 1948 Pennsylvania study (2). Travel-time-consumption rates are graphically illustrated for the two studies in figure 8, using the average rates for all vehicles.

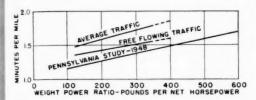


Figure 8.—Comparison of 1957-58 travel time rates for rural line-haul gasolinepowered trucks for 1.2 rate of rise and fall with 1948 Pennsylvania study data based on 1.3 rate of rise and fall.

The time-consumption rates obtained in the 1958 study, considering the average travel time for all conditions of traffic, are labeled "average traffic" in figure 8 and were found to be 26 percent higher than corresponding data reported in the Pennsylvania study. A comparison of greater significance, however, can be made between the 1958 study, identified in figure 8 as "free-flowing traffic," and those of 1948 Pennsylvania study, because both were made under similar conditions. The time-consumption rates of gasoline-powered trucks traveling in free-flowing traffic were 10 percent higher than corresponding data reported in the Pennsylvania study.

Effect of Traffic on Performance

One of the main objectives of the study was to investigate the effect of varying traffic volumes on the performance of commercial vehicles. Other studies (1—4) have made a good start in determining the fuel consumption and travel time for uniform speeds, stops and starts, and slowdowns; and in finding out how certain factors, such as gradient, rise and fall, horizontal curvature, gross vehicle weight, and engine characteristics, effect fuel and time consumption. However, little has been available in the literature as to the effect of varying traffic volumes.

It was hoped that this study would provide a means for estimating the added operating cost brought about by frictions in the traffic stream. The basic approach was one of considering the number of speed changes per mile for varying volume conditions, the percentage of the total number of speed changes that were stops and starts, and the average speed change in terms of miles per hour of a stop or slowdown. It was reasoned that if such information could be provided, the added cost for having to operate other than at a uniform speed could readily be assessed.

Speed changes per mile

What are probably the most significant results of this study, speed changes per mile, were computed for trucks with different groweights operating over three types of run; highways with varying average daily

traffic and are shown in table 11. An attempt was made to develop similar data for urban operation, but the lack of traffic data for the irregular routes traveled made this impossible.

The average values of speed changes per mile (from table 11) are shown in figure 9 as straight-line relationship established for the three types of highways. The benefits accruing from the elimination of impediments to free-flowing traffic are clearly illustrated by comparing the speed changes per mile on the 4-lane divided, controlled-access facility with those on the 4-lane undivided, uncontrolled-access facility. For an average daily traffic of 15,000 vehicles, there were an average of 2.0 speed changes per mile on the 4-lane uncontrolled-access highway as compared with a rate of about 0.8 on the 4-lane controlled access highway. Speed changes per mile on 2-lane highways increased from 2.0 to 2.8 where the average daily traffic increased from 5,000 to 10,000. In contrast, speed changes per mile on the 4-lane uncontrolled-access highway increased from 1.5 to 1.8 over the same average daily traffic

Data for 4-lane divided highways with no access control were not obtained in sufficient quantity for analysis. It is reasonable to expect that the relationship for this type of highway would fall between that for the two 4-lane highways shown in figure 9, and would probably lie closer to the 4-lane undivided, uncontrolled-access highway.

Analysis of speed changes

Of considerable importance among the data obtained were the percentages of total speed changes representing stops and slowdowns. Speed changes caused by stops and slowdowns are presented in table 12 from results of the studies made in Ohio and Washington, the only States where stops were recorded. On the average, complete stops occasioned about 11 percent of the speed changes in rural line-haul operations and about 45 percent in urban line-haul operations.

Compiled from the limited data available, an analysis of speed changes in miles per hour was made and it was found that an average stop in rural areas was made from a speed of 26 miles per hour. On city streets the average stop was made from a speed of 18.9 miles per hour. The average change in speed for slewdowns in both rural and urban areas was 11.4 miles per hour.

To illustrate the significance of a speed change in terms of motor-fuel consumption and to confirm that fuel consumption increases with an increasing number of speed changes per mile, gasoline-consumption rates were computed for road sections having different rates of speed change per mile, for different gross vehicle weights. The average rates are presented in table 13 for the three types of operation.

The straight-line relationships established for the data in table 13 are shown in figure 10. It is seen that an increase of one speed change

Table 11.—Speed changes per mile made by trucks operating over three types of rural highways with varying average daily traffic

Average daily traffic on indicated highways	Highway section	Number	Total miles	Spee		es per mil nicle weig				e gross
	mileage	trips	traveled	17.0	23. 1	27.4	36. 3	43.7	52.2	Average
4-lane divided, con- trolled access: 46,700 23,300 12,700 4-lane undivided, un- controlled access:		54 54 54	354. 24 195. 48 442. 46	1.56 .62 .38	2.05 .83 .62		2. 38 1. 17 . 53	2.71 1.90 .66	2. 36 1. 99 . 74	2. 19 1. 24 . 60
15,700		54 54 52	1, 712, 34 2, 634, 12 153, 79	1.73 1.59	1. 79 1. 55 1. 19		2. 12 2. 07 1. 58	2. 35 2. 03 1. 47	2. 34 2. 12 1. 73	2.03 1.82 1.53
8,800 6,000 2,000	27. 30 57. 58 20. 52	56 56 56	1, 528, 80 3, 224, 48 1, 149, 12			2.75 2.24 1.59	2.74 2.14 1.48	2. 61 2. 15 1. 35	2. 69 2. 31 1. 70	2.71 2.18 1.50

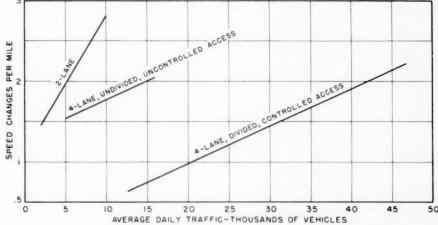


Figure 9.—Average speed changes per mile for rural line-haul trucks, by average daily traffic and type of highway.

Table 12.—Number and percentage of speed changes occasioned by slowdowns and stops of trucks in Washington and Ohio rural and urban line-haul travel

	Washington				Ohio			Total	
Speed Changes	Slow- downs	Stops	Speed changes	Slow- downs	Stops	Speed changes	Slow- downs	Stops	Speed
Rural line-haul: Number Percent	5, 358 87. 1	795 12. 9	6, 153 100. 0	8, 036 89. 6	935 10. 4	8, 971 100. 0	13, 393 88. 6	1,731 11.4	15, 124 100. 0
Urban line-haul: Number Percent	1, 220 66. 6	613 33. 4	1, 833 100. 0	1, 581 48. 4	1, 688 51. 6	3, 269 100. 0	2, 801 54. 9	2, 301 45. 1	5, 102 100. 0

per mile for a vehicle weighing 30,000 pounds traveling on a rural highway resulted in an average fuel-consumption increase of 0.010 gallon per mile. The corresponding increase for vehicles in urban line-haul operation was 0.021 gallon per mile, and for city delivery vehicles the average increase was 0.0056 gallon per mile. The greater rate of speed change for urban line-haul operation as compared to rural line-haul operation is probably due to the higher incidence of stops and slowdowns. City pickup and delivery vehicles consume less gasoline per speed change than the urban line-haul vehicles because stops and slowdowns are of lesser magnitude, as evidenced by an average speed of 11 miles per

Also of importance is the indication that fuel consumption attributable to a speed change increases with gross vehicle weight. For example, the fuel consumed for an increase of one speed change per mile for rural line-haul operations was 0.0092 gallon for vehicles with 20,000 pounds GVW and 0.0142 gallon for 50,000 pounds.

Data for travel time-consumption rates due to one speed change per mile were also developed, and are shown in table 14. The average time-consumption rate did not appear to increase with gross weight but the average value for all gross vehicle weights increased as the speed changes per mile increased.

The average time consumed in one speed change for rural line-haul operation was found to be 0.26 minute, or 15.6 seconds; for urban line-haul operation 0.27 minute, or 16.2 seconds; and for city pickup and delivery operation 0.38 minute, or nearly 23 seconds. In spite of the fact that the speeds from which stops and slowdowns were made were higher in rural than in urban line-haul operation, the time consumption per speed change is about equal, probably because the percentage of total speed changes that are stops is much higher in the urban line-haul.

The increased fuel- and time-consumption rates for one speed change have been developed principally for illustrative purposes, although they can be used in estimating benefits. When data are available from controlled tests (3-4) on a variety of vehicles, the data herein presented may be refined.

Tal

pou

save

and

com

of a

con

Thu

mea

con

mer

tha

K

Cost of a Speed Change

The approximate cost of a stop is included in this article more as a matter of interest than with the idea of establishing valid cost values. Many sections of rural highway studied were traveled by line-haul vehicles without experiencing any stops and with less than two slowdowns per mile. Likewise, certain urban sections of highway studied were traveled by line-haul vehicles with a high incidence of stops but with less than two slowdowns per mile.

In order to estimate the cost of a stop the entire fuel consumption rate for the rural travel with no stops was subtracted from the fuel-consumption rate for urban travel where a high incidence of stops occurred. The difference is attributed solely to the effect of stops because slowdowns were the same in both instances. It should be remembered though. that the average stop was made from 26 miles per hour in rural areas and 19 miles per hour in urban areas. Dividing the total consumption per mile due to traffic stops by the number of stops per mile gave the consumption rates per stop which are shown in table 15. Gasoline consumed per stop showed a definite increase as the GVW increased. For example, if a cost per gallon of fuel of 30 cents is used, the cost of a stop would range

SPEED CHANGES
PER MILE

20

100
10 20 30 40 50 60 70

LINE HAUL-URBAN

20

100
10 20 30 40 50 60 70

CITY PICKUP AND DELIVERY

20

GROSS VEHICLE WEIGHT-THOUSANDS OF POUNDS

Figure 10.—Gasoline consumption rates, by rate of speed change per mile and by gross vehicle weight, for line-haul and city delivery vehicles.

Table 13.—Gasoline-consumption rates for trucks in line-haul and city pickup and delivery operation for various rates of speed change per mile

Average gross vehicle weight (pounds)	Gasoline	e-consumpt		n gallons p I changes p		indicated	number
	1	3	4	5	7	9	12
Line-haul, rural:							
17,000	0.134	0.142		0.160	0.181		
34,500	. 180	. 198		. 226	. 250	******	
42,000	. 200	. 222		. 255	. 279		
53, 000	. 228	. 257		. 300	. 322		
57,000	. 239	. 270		. 311	. 022		
68,000	. 268	. 305				22000	9-2
180,000	. 200	. 303					****
Average	. 197	. 220		. 251	. 279	*****	
Line-haul, urban:	. 101	. 220		. 401	. 210	*****	
17,000	0.143	0.149		0.153			
26,000	. 159	. 180		. 198	******	0.324	
28,000	. 100	. 160		. 100	0.246	0. 024	
52,000	. 206	. 268	******	. 328	. 409	. 426	
58,000	. 217						
59,000		. 292			457	******	
61 000		1 200	******	.373			
61,000						. 465	
62,000.	****				*****	. 400	
Average	. 185	. 224		. 269	. 333	. 382	
City pickup and delivery:	. 100			. 200	. 000	. 004	
6,000_		******	0.111				0.145
10,500		******	. 131				. 167
18,500	******		. 165	i .	1		. 206
27,500	******		. 204				250
33,300		*****	. 229	******			. 279
Majorat.		*	. 4.20				. 210
Average			. 143		1	1	. 168

PUE

Table 14.—Average travel time-consumption for trucks in line-haul and city pickup and delivery operations for various rates of speed changes per mile

Type of travel	Average time consumption in minutes per mile for the indicated number of speed changes per mile							A verage time lost per speed
	1	3	4	5	7	9	12	change (minutes)
Rural Urban. City pickup and delivery	1. 48 2. 35	1.89 2.69	4. 39	2. 33 3. 20	3. 05 3. 81	4. 53	7.43	0. 26 . 27 . 38

from one-half cent for a GVW of 17,000 pounds to more than 2 cents for a GVW of 51,000 pounds.

n s. e o n

e e

ie

of h

h,

y

in

by by nd Knowing the number of speed changes saved, the proportion of stops and slowdowns, and the magnitude of each, it is possible to compute the added cost of fuel and travel time of a speed change if the extra fuel and time consumed during the speed change is known. Thus, using speed changes per mile as a measure of congestion, the benefits may be computed that accrue from highway improvements that reduce congestion. It is realized that at present the tool is rough, but it can be

refined. This is planned, using digital recorders instead of human observers.

References

(1) BEAKEY, JOHN

The effect of highway design on vehicle speed and fuel consumption. Oregon State Highway Commission Technical Bulletin No. 5, Salem, 1937.

(2) SAAL, CARL C.

Time and gasoline consumption in motor truck operation. Highway Research Board, Research Report No. 9-A, 1950.

Table 15.—Gasoline consumption rates for trucks in line-haul operation due to traffic stops, by gross vehicle weight

	Gallons per stop			
Gross vehicle weight (pounds)	Actual rate	Computed rate 1		
17,000 21,300 27,000 34,500	0. 014 . 030 . 034 . 044	0. 017 . 024 . 034 . 046		
42,000 51,200	. 054	. 058		

 1 Computed from straight line formula 0.001625W - 0.0103. ($\rm W=G\,VW$ in thousands of pounds.)

(3) CLAFFEY, PAUL J.

Time and fuel consumption for highway-user benefit studies. See pp. 16-21 of this issue of Public Roads.

(4) SAWHILL, ROY B.

Motor transport fuel consumption rates. Highway Research Board paper, 39th Annual Meeting, Jan. 1960.

New Publication: Highway Progress, 1959

The Annual Report of the Bureau of Public Roads, Fiscal Year 1959, newly titled *Highway Progress*, 1959, is now available from the Superintendent of Documents, U.S. Government Printing Office, Washington 25, D.C. at 40 cents a copy.

Reflecting the central role of highway transportation in our entire way of life, the greatly expanded construction program launched by the Federal-Aid Highway Act of 1956 continued its vigorous growth during the fiscal

year.

Highway usage also increased, with motorvehicle registrations forecast to reach a record high of 70.4 million in the calendar year 1959, and travel by these vehicles pointing toward at least 700 billion vehicle miles.

The Bureau of Public Roads had set a fiscal year goal of \$3.075 billion in Federal-aid obligations for surveys and plans, right-of-way acquisition, and construction. Actual obligations of the year reached \$3.223 billion, as compared with a \$2.749-billion total for the previous year.

During the fiscal year 1959, completions of all classes of Federal-aid and Federal projects provided improvements on 32,828 miles of roads and streets—with the growing use of multilane highways—that total represented the equivalent of 71,336 miles of single-lane construction. Individual projects included examples of the most spectacular and the most complex construction in highway history. Construction put in place during the year called for \$2.875 billion of Federal funds, an increase of 74 percent over the previous year.

Projects for the construction of 30,923 miles of improvements also were set up during the year under the Federal-aid and Federal highway programs.

These extensive Federal-aid operations were supported largely with funds authorized by the Federal-Aid Highway Acts of 1956 and 1958. On August 1, 1958, Federal-aid funds for fiscal year 1960, amounting to \$3.5 billion, were apportioned to the States. This brought the total of Federal-aid apportioned since passage of the 1956 Act to \$10.55 billion.

Federal-aid improvements under the continuing primary, secondary, and urban programs progressed on a larger scale than ever before, but the Interstate System held its position as the focal point of public interest in highways. As sections were opened to traffic, more and more motorists began experiencing the advantages of the controlled-access freeway with its relief from cross traffic, its greater comfort and safety, and significant savings in travel time and vehicle operating costs. Residential, commercial, and industrial centers developed adjacent to the Interstate right-of-way—further indication of the catalytic role of motor transport.

Locating such important highway facilities was not left to chance. These complex Interstate System projects usually require several years of preparatory work—planning and surveying, plus design and right-of-way acquisition—before actual construction begins. The progress report on the Federal-aid highway program, presented to Congress during the fiscal year, showed that by December 31, 1958, improvements substantially meeting approved standards and at least adequate for current traffic, had been completed on 4,831 miles of the Interstate System and that during the calendar year 1958, there were 2,078 miles of high type pavement placed under construction.

At the end of the fiscal year progress of the Interstate System program was threatened by two financial problems. The first was immediate, and eminated from a sharply accelerated rate of spending called for by the Federal-Aid Highay Act of 1958.

Under the basic 1956 Act, the Federal-sid program is financed on a pay-as-you-go basis from Federal highway-user taxes which go into the highway trust fund. Net income of the trust fund during the fiscal year was \$2.2 billion while expenditures from the fund for Federal-aid highways amounted to \$2.6 billion. This was the first year that expenditures had exceeded receipts. Apportionments for fiscal 1960, made under the 1958 Act, considerably outweighed anticipated revenues to the trust fund. It was recognized that this action would deplete the surplus accumulated through earlier years of the trust fund and would preclude apportionment of any funds for the Interstate System for the fiscal year 1961. As the fiscal year 1959 ended, congressional action to remedy this situation was pending.

There was, in addition, a long-range problem of financing the Interstate System program. The new estimate of the cost of completing the Interstate System presented to the Congress during fiscal year 1958 showed that Federal and State matching financing required after July 1, 1956, amounted to \$37.6 billion, as compared with the \$27.4-billion figure contemplated in the Federal Aid Highway Acts of 1954 and 1956.

During fiscal year 1959 the Bureau of Public Roads submitted the *Third Progress Report of the Highway Cost Allocation Study*. Scheduled for presentation to Congress early in 1961, together with a new detailed estimate of the cost of completing the Interstate System, it is expected that these reports will be of real assistance to the Congress in its consideration of appropriate scheduling and financing of Interstate and other Federal-aid highway programs.

Errata

The table State Legal Maximum Limits of Motor Vehicle Sizes and Weights Compared With AASHO Standards, which appears on pages 250–251 of Public Roads magazine, vol. 30, No. 11, December 1959, requires a correction in footnote references.

In the entries for Maryland and Ohio, the footnote references 31 and 44 should be deleted from the column "Axle load-pounds, Tandem, Statutory limit." In the entry for North Dakota, footnote reference 44 should be added in the "5-axle" and "Other combination" columns under the heading "Practical maximum gross weight."

PUBLICATIONS of the Bureau of Public Roads

A list of the more important articles in Public Roads and title sheets for volumes 24-29 are available upon request addressed to Bureau of Public Roads, Washington 25, D.C.

The following publications are sold by the Superintendent of Documents, Government Printing Office, Washington 25, D.C. Orders should be sent direct to the Superintendent of Documents. Prepayment is required.

ANNUAL REPORTS

he

id sis

of as ad 2.6 d-n-58 ed

ed

us

he

nt

he

59

his

b-

ro-

m-

to

ed

ng

to

ral

lic

of

led

61,

he

is

eal

on

of

ay

Annual Reports of the Bureau of Public Roads:

1951, 35 cents. 1952, 25 cents. 1955, 25 cents. 1958, 30 cents. 1959, 40 cents. (Other years are now out of print.)

REPORTS TO CONGRESS

- A Report of Factors for Use in Apportioning Funds for the National System of Interstate and Defense Highways, House Document No. 300 (1958). 15 cents.
- Consideration for Reimbursement for Certain Highways on the Interstate System, House Document No. 301 (1958). 15 cents.
- Factual Discussion of Motortruck Operation. Regulation, and Taxation (1951). 30 cents.
- Federal Role in Highway Safety, House Document No. 93 (1959), 60 cents.
- First Progress Report of the Highway Cost Allocation Study, House Document No. 106 (1957). 35 cents.
- Highway Needs of the National Defense, House Document No. 249 (1949). 50 cents.
- Interregional Highways, House Document No. 379 (1944). 75 cents.
- Local Rural Road Problem (1950). 20 cents.
- Needs of the Highway Systems, 1955–84, House Document No. 120 (1955). 15 cents.
- Progress and Feasibility of Toll Roads and Their Relation to the Federal-Aid Program, House Document No. 139 (1955). 15 cents,
- Progress Report on the Federal-Aid Highway Program, House Document No. 74 (1959). 70 cents.
- Public Utility Relocation Incident to Highway Improvement, House Document No. 127 (1955). 25 cents.
- That Progress Report of the Highway Cost Allocation Study House Document No. 91 (1959). 35 cents,

PUBLICATIONS

- Catalog of Highway Bridge Plans (1959). \$1.00
- Construction of Private Driveways, No. 272MP (1937). 15 cents.
- Criteria for Prestressed Concrete Bridges (1954). 15 cents.
- Design Capacity Charts for Signalized Street and Highway Intersections (reprint from Public Roads, Feb. 1951). 25 cents.
- Financing of Highways by Counties and Local Rural Governments: 1942-51, 75 cents,
- General Location of the National System of Interstate Highways, Including All Additional Routes at Urban Areas Designated in September 1955. 55 cents.
- Highway Bond Calculations (1936), 10 cents.
- Highway Capacity Manual (1950). \$1.00.
- Highway Statistics (published annually since 1945): 1955, \$1.00. 1956, \$1.00. 1957, \$1.25.
- Highway Statistics, Summary to 1955. \$1.00.
- Highways of History (1939). 25 cents.
- Legal Aspects of Controlling Highway Access (1945). 15 cents.
- Manual on Uniform Traffic Control Devices for Streets and Highways (1948) (including 1954 revisions supplement). \$1.25.

 Revisions to the Manual on Uniform Traffic Control Devices

for Streets and Highways (1954). Separate, 15 cents.

- Parking Guide for Cities (1956). 55 cents.
- Public Control of Highway Access and Roadside Development (1947). 35 cents.
- Public Land Acquisition for Highway Purposes (1943). 10 cents.
- Results of Physical Tests of Road-Building Aggregate (1953), \$1.00.
- Selected Bibliography on Highway Finance (1951). 60 cents.
- Specifications for Aerial Surveys and Mapping by Photogrammetric Methods for Highways, 1958: a reference guide outline. 75 cents.
- Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects, FP-57 (1957). \$2.00.
- Standard Plans for Highway Bridge Superstructures (1956). \$1.75,
- Transition Curves for Highways (1940). \$1.75.

UNITED STATES GOVERNMENT PRINTING OFFICE

DIVISION OF PUBLIC DOCUMENTS

WASHINGTON 25, D.C.

OFFICIAL BUSINESS

If you do not desire to continue to receive this publication, please CHECK HERE :; tear off this label and return it to the above address. Your name will then be removed promptly from the appropriate mailing list.

PENALTY FOR PRIVATE USE TO AVOID PAYMENT OF POSTAGE, \$300 (GPO)

P

PI B

P

0 W